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~~ALEX. AGASSIZ.~~

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THE

THEORY OF COLOR

IN ITS RELATION TO

ART AND ART-INDUSTRY.

BY

DR. WILHELM VON BEZOLD,

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Translated from the German

BY

S. R. KOEHLER.

WITH AN INTRODUCTION AND NOTES

BY

EDWARD C. PICKERING,

THAYER PROFESSOR OF PHYSICS AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

AUTHORIZED AMERICAN EDITION.

REVISED AND ENLARGED BY THE AUTHOR.

ILLUSTRATED BY CHROMO-LITHOGRAPHIC PLATES AND WOODCUTS.

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PREFACE

TO THE AMERICAN EDITION.

IN addressing these few words to the reader, at the request of the publishers, I may as well observe at the outset that the present work is not simply a translation, but in reality a new edition, which may justly be called enlarged and improved.

All the knowledge gained since the appearance of the first (German) edition has diligently been made use of; passages, the understanding of which seemed to offer difficulties, have been rewritten; voids have been filled; and the results of recent investigations have been introduced at the proper places. But beyond all this, the book has been enriched with an additional number of colored plates, which, I believe, will be found to have materially enhanced its value, and which will contribute largely to a clearer understanding of the text.

The animated correspondence which was kept up during the progress of the translation between Mr. Koehler and myself, and in which all passages that appeared to be obscure were thoroughly discussed, together with the kind aid extended by Professor Pickering as far as the purely physical part of the work is concerned, are a sufficient guaranty that

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the English version in all its parts offers a perfectly correct rendering of the ideas of the original.

There is one point, however, which I should here like to dwell upon somewhat more at length, i. e. the choice of terms for the designation of some of the colors. Peculiar difficulties had to be overcome in this respect, even in the German language, since several of the names, which are familiar to the physicist, are entirely unknown to the artist, while dyers and weavers employ still other designations, which are again different from those used by either of the two classes first named. I therefore resolved to depart from the usages of physical terminology in a few instances in which this terminology would be likely to give rise to decided misunderstandings, and I cannot refrain from expressing a strong hope, that these changes may be sanctioned and adopted by my colleagues in the profession. It seems well, at all events, to call attention to these changes here, and to give a concise statement of the reasons which induced them.

The first relates to the replacing of the term "indigo" for a part of the spectrum by "ultramarine," as this latter pigment is much better fitted to represent the corresponding spectral color.

Again, I have replaced the term "cyanogen-blue," which, as far as I know, originated with Helmholtz, by the term "turquoise-blue," as the former would necessitate a special definition, while the latter is perfectly clear to all those who have once seen the half-precious stone in question.

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If such difficulties had to be met in writing the book, even in the mother-tongue, it is but natural that they should assert themselves still more decidedly in the translation into a foreign language. The word "purple," for example, is employed by English as well as by German physicists to designate a hue which is situated between red and violet. The German artists likewise use the word in the same sense, while no definite idea whatever attaches to it in ordinary usage. In English, on the contrary, "purple" is generally understood to designate a color which other nations, and also the English physicists, call "violet," and the second, original meaning of the word has only been preserved to a certain degree in the "royal purple" of the poets.

The modern art of the dyer has a variety of names for the different shades of this color, all of which shades can be most beautifully produced by combinations of aniline, and which are known to commerce as "Magenta-red," "Solferino-red," "Garibaldi-red," etc.; but all these designations are too much exposed to the caprices of the ever-changing fashions, to make it desirable to adopt either of them in place of the word "purple." The term "crimson," which is sometimes used for these hues by artists, also appeared to be too indefinite, especially as in German crimson, or *carmoisin*, has a meaning which is different from that attaching to carmine.

The word "purple" has therefore been retained,

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and has been used throughout in the sense in which it has become naturalized in physics.

Similar difficulties made themselves felt in a number of other cases, and I must therefore urgently request my readers, for the sake of securing a clear understanding, to pay special attention to those passages in which it has been attempted to define with scientific accuracy the somewhat loose terms commonly in use.

As to the leading ideas which have served as a guide in the construction of the whole work, I have already expressed myself in detail in the preface to the German edition. I will therefore confine myself to adding that, in regard to the experiments described, I have followed a principle which differs entirely from that usually followed in modern popular works on science. For while in these works there will generally be found descriptions of brilliant exhibitions, which have been given at great cost before vast audiences, it has on the contrary been my desire as much as possible to bring all experiments into a form which will admit of their being repeated even by the unprofessional reader, and with the most simple materials.

Nothing now remains to be done by me, but to give utterance to the wish that the reception accorded to the book may correspond to the careful labor bestowed upon it by the translator as well as by the publishers, for the purpose of making it accessible to the Anglo-American public.

THE AUTHOR.

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PREFACE.

MOTTO:

Studia prima la scienza, e poi seguita
la pratica nata da essa scienza.

LIONARDO DA VINCI.

THE author does not conceal from himself the fact, that the book which he is about to offer to the public will have to encounter a widespread prejudice, more especially among those for whom it is principally intended.

The opinion is frequently met with, that the most glorious creations of the fine arts owe their origin almost exclusively to an inborn talent, which has been developed by long-continued practice; while, on the other hand, it is believed that scientific investigations into questions of art are of but small value to true genius, and that, at the very best, they can only help mediocrity to attain to achievements of questionable merit.

Curiously enough, history teaches us that the most prominent artists did not share this opinion. The great heroes of art, those men whose works betray a master's hand in every line, exerted themselves most zealously to replace purely instinctive effort by conscious activity, and to inquire into

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the causes which underlie all successful creative production. Although nothing was more foreign to them than the idea that technical skill must be looked upon as the ultimate aim of their studies, they nevertheless neglected nothing which appeared to be calculated to make them thorough masters of their craft. And for the purpose of reaching this aim they were quite as earnest in devoting themselves to scientific studies, as they were well assured that the perfect control of all outward aids is absolutely necessary, if the emancipated intellect is to be enabled to soar to the highest realms of art without being hindered by petty limitations.

To prove the truth of the assertion just made, it will be sufficient to recall the names of LIONARDO DA VINCI, of ALBRECHT DÜRER, and of RAFAEL.

LIONARDO made anatomy and perspective the subjects of his study, and was one of the first to devote considerable attention to color. His investigations in these departments are so thorough and so important, that an enduring place is secured to his memory in the history of science. DÜRER wrote on geometry, not to speak of his work on fortification, since this latter has no connection with his artistic activity. And even in the case of RAFAEL, who may be taken as a pre-eminently fitting example of a genius "by the grace of God," the evidence is not wanting which proves that he did not regard severe scientific study as superfluous; for sketches by him are still extant, show-

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ing the figures which in his large paintings appear draped, not only naked, but even as skeletons.

Since the days of these great men the conviction has taken root, that no artist can get along without a knowledge of anatomy and of perspective.

It is different, however, with the theory of color. The attempts made to build up this theory, as applied in art, upon a similarly secure basis, and to place it alongside of the other two sciences, as their peer, have not, so far, been very successful.

To be sure, it cannot be denied that, from the very start, these three sciences occupy a somewhat different position in relation to art. While it is simply impossible to paint a tolerably decent picture without a knowledge of anatomy and of perspective, masterpieces of color and exemplary ornaments were produced at a time when a theory of color, based upon scientific principles, could not be thought of.

Nevertheless, the works of prominent colorists show a very consistent application of certain expedients, and it does not admit of a doubt that these masters had formulated, at least for their own use, fixed systems for the treatment and the application of color, which may perhaps have been handed down as traditions to their personal scholars, but which others can only reconstruct with difficulty from their works.

Such systems cannot become common property, unless it should be possible to give to them a scientific expression.

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But in appealing to bygone times, we must take good care not to forget that the position occupied by art to-day is different from that which it formerly held. As long as art — which must here be understood as likewise embracing the art-industries — is in a condition of steady and quiet development, the individual artist may in a measure be looked upon as simply an interpreter of the many. He gives expression to the ideas and to the efforts which animate all of his surroundings; he is held up and led on by the feelings and the taste of his nation and of his age, which develop themselves in accordance with an inner necessity. The iron logic of history and the healthy common-sense of the people as a whole, which it is so exceedingly difficult to repress, guard him from grave errors; while on the other hand, in times of decay, they are quite as inexorable in forcing him to follow the current.

Different conditions, however, assert themselves in our own day, in which the rapidly growing means of intercommunication throw the productions of all nations and of all schools promiscuously upon the market; in which the increasing historical interest brings to light the works of art of past periods, and compels everybody to make himself familiar with them; and in which the spirit of invention, incessantly working in feverish haste, is continually producing new tools and new materials, before those which have hardly been acquired have had time to be thoroughly

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comprehended and artistically applied. Under such circumstances it is necessary to call in the aid of a judgment refined by science and quickened by severe thinking, if taste is not to be led astray, and the feeling for the truly organic construction of a work of art is not to be stifled by the impressions rushing in from all sides.

The best evidence of the truth of the assertion just made — i. e. that theoretical studies are to-day of far greater importance for art than formerly — is furnished by architecture. While magnificent works were produced in past periods by masters who hardly had any idea of the history of art, it is absolutely impossible at present to conceive of any great architectural achievement without a thorough preparation in this branch of knowledge.

But, aside from the influence which all studies of this kind — including, of course, studies on the effects of color — must exercise upon the education and the purification of the artistic feeling, it is also to be considered that, from purely technical motives, and especially on the part of the art-industries, it is often felt to be desirable to possess the results of experience in a well-defined and fixed form. This is more especially true of those branches of art-workmanship which are compelled to employ colors that have been fixed upon beforehand, such as the weaving of colored stuffs, for instance, or the manufacture of paper-hangings, chromolithography, and similar art-industries. In problems of this

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class the artist does not enjoy the same liberty as in painting. It is denied to him to approach nearer and nearer to the picture which may be present to his mind, by minute changes in the hues of the colors, introduced during the progress of the work; but he must, on the contrary, know to a certainty from the very beginning what effect the chosen colors will have when combined together in the shape of a work of art. Even by the use of a painted sketch this difficulty can be obviated only to a very small degree. For, on the one hand, we are especially subject to great delusions in judging of the colors composing a certain pattern, which delusions can only be avoided by varied experience or by scientific knowledge; while, on the other hand, the use of a new material will also be the cause of new effects of light, so that the colors will appear to be considerably changed if the same pattern is executed in the same hues, at one time in wool, at another in silk, or whether the fabric selected be velvet or satin.

And, indeed, the first attempt of any importance to produce a practical theory of colors was induced by art-industry; for the celebrated chemist CHEVREUL, who undertook this task, was prompted to it by his situation as chief of the manufactory of Parisian gobelins, owned by the government of France. It became clear to him that the complaints of the workingmen about the performances of the dyeing establishment connected with the manufactory were really not to be laid at the door of this

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establishment, but that they had their foundation in the *apparent* changes which the colors underwent when in juxtaposition with others, i. e. in so-called effects of contrast. Chevreul therefore characterized the whole of his work as the theory of "*simultaneous contrasts.*"

The great extent which these apparent changes of colors in juxtaposition can assume is well illustrated by an incident cited by Chevreul. A merchant and a silk-weaver were involved in a lawsuit, which owed its origin simply and purely to such an effect of contrast. The merchant had delivered black silk and blue silk to the weaver, which was to be made into ribbon. After the delivery of the ribbon, the merchant insisted that the silk had been exchanged, as it was of a brownish black, while that given to the weaver was of a deep black. The merchant, however, wronged the weaver completely, for the change in the silk was only apparent, having been brought about by the juxtaposition of the blue, and, in addition to this, strengthened by the peculiarities of the web which had been chosen.

The investigations of Chevreul were received with the greatest interest by the French manufacturers, so much so, that the Chamber of Commerce of Lyons prevailed upon him to write a special treatise on the optical effects of silken fabrics, — a proof, well worthy of being taken to heart, that the French manufacturers do not rely simply upon their innate taste for the art-industries, but that they seize

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with avidity upon everything calculated to aid their efforts in this direction.

But, however valuable Chevreul's works on the theory of color may be, they treat too exclusively of the effects of contrast on the one hand, while on the other they are the offspring of a time when the nature of the mixture of colors was as yet too little understood to allow of the idea of constructing a system of color upon a secure basis.

Such a construction became possible only after the pioneer investigations of HELMHOLTZ had made clear the difference between the mixture of *colors* and of *pigments*, and after he, as well as MAXWELL, had fixed the laws of the true mixture of colors by the aid of convincing experiments.

The physical and the physiological side of the theory of color had first to be sufficiently developed by these investigations, before it could be made available as a basis for practical æsthetic inquiries.

An attempt of this kind was made ten years ago, by BRÜCKE, in a work which he entitled "The Physiology of Colors," and in which he digested all the material at hand, while at the same time he enriched it by a great many subtle observations and highly interesting remarks. But in spite of its merits this work has penetrated but little into the sphere for which it was especially intended, and another similar attempt may therefore be justifiable.

This is the aim of the present work. It is

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intended to make artists and persons engaged in art-industrial pursuits familiar with the results of investigation, presented in the simplest possible form, and it is to show how the various propositions which have been laid down may be made available, either in the creation of new works, or for the comprehension of those already existing.

Accordingly I have presupposed no knowledge whatever in physics, but have endeavored to present a whole that shall be complete in itself, and have chosen a manner of treatment which will be easy of comprehension to every person of education.

In this endeavor I was materially assisted by the publisher, who met all my wishes in regard to wood-cuts and plates with the greatest readiness.

The leading principles in the first four chapters are of a purely physical nature; but the illustrations, as well as the materials necessary for the experiments, have been selected as much as possible from the sphere, both ideal and practical, in which artists are accustomed to move. This appeared to be necessary for the purpose of continually keeping in view the close connection of the statements made, and of the experiments described, with the special activity of the artist.

Such a treatment naturally demanded a pretty thorough, independent manipulation of all the scientific material bearing upon the subject, so that the book will probably not be devoid of interest even to the specialist, although, from the

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very nature of its tendency, it is not devoted to severe scientific investigation.

Many readers will perhaps be loath to miss all attempts at a critical estimation, and a refutation, of GÖTHE's theory of color. The author preferred, however, principally from a feeling of veneration for the great poet, to let the facts which have been brought to light by rigorous scientific research speak for themselves, instead of entering upon the critical examination of a work which never exercised any lasting influence upon the development of science, and which has been excellently well refuted long ago.

An essential difference will be noticed between the first four chapters and the last chapter. While the contents of the former are largely of a physical and physiological character, the fifth chapter will be found to be principally devoted to the artistic and the art-historical aspect of the theory of color.

In regard to this point I must, however, most urgently entreat all specialists to be lenient with me; and I must lay especial emphasis upon the fact that I am neither a professional student of æsthetics nor an art-historian, and that I have never had the opportunity of making thorough literary studies in these branches. My knowledge and my judgment in matters of art I owe almost exclusively to the collections of my native city, Munich, and to the intercourse with the artists whose friendship I enjoy.

I was nevertheless compelled to venture the

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attempt to penetrate into this to me somewhat foreign department, as it was the only possible means for bringing to a close the chain of individual investigations, and for showing the practical and æsthetic importance of the propositions in physics which had previously been developed.

Those readers, therefore, to whom the physical investigations may at first appear to be rather unattractive, will do well to begin with the last chapter, deferring the real study of the book until they have themselves felt the want of a secure basis.

The aim and the scope of the work have undoubtedly been sufficiently characterized by what has been said above. It is intended to connect, by an intellectual chain, the mass of isolated observations which every artist must make, and continues to make daily; to awaken and to intensify the interest in, and the feeling for, color; and to increase and to purify the comprehension of its importance in art.

May the book everywhere succeed in awakening the same interest in its subject which called it into being!

THE AUTHOR.

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INTRODUCTION.

THE phenomena of Light are now commonly explained by the Undulatory Theory. This assumes that all space is filled by a medium called ether, almost infinitely more rare than the most attenuated gas, and that the passage of minute vibrations through this medium gives rise to the effect which we call light. The motion of the ether is at right angles to the direction of the light, so that when the sun is overhead the motion of the ether is horizontal. Such vibrations, like the waves of water, are said to be transverse. The intensity or brightness of the light is dependent on the amount of motion of the ether, or height of the wave, while variations in the length of the wave give rise to the phenomena of color. The key to the best method of studying the laws of color was found by Newton when he showed that the prism was capable of decomposing light into its primitive colors. It thus appears that a beam of sunlight, instead of consisting of a simple system of waves, is really composed of a collection of rays of an almost infinite variety of wave-lengths. When the longer waves fall on the retina they produce the sensation which we call red. As the waves gradually diminish in length, we obtain in turn the effect of yellow, green, blue, and violet. Rays of greater and less length than these are also commonly present in white light, but as they do not affect the retina they are invisible. Other means must there-

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fore be employed to detect them. A blackened thermometer bulb readily absorbs the longer waves and serves to mark their presence, while it is but little affected by the shorter waves of green, blue, or violet light. On the other hand, a sensitized photographic plate is but little changed by the longer red rays, but quickly alters under the influence of the blue or violet waves. Formerly these effects were supposed to be due to three different kinds of waves, those of light, heat, and chemical action. There appears, however, to be no real difference between them except in degree, and the light, heat, and chemical action should rather be regarded as three manifestations of the same power, which is sometimes called radiant energy. A proof of this is found in the fact that if we employ light of uniform wave-length, as the flame of a spirit-lamp with salt on its wick, we find that, however we alter its brightness, the heat, light, and chemical action all alter in the same proportion. If now we use a beam of white light, this rule seems no longer to hold. For instance, by a plate of clear glass, or better, by a thin layer of water, we may cut off a large portion of the heat while the light is affected but little. Again, interposing a plate of blue glass will diminish the light and heat far more than the chemical action. The explanation is, however, quite simple. In the first case, the glass cuts off in a great measure the waves of length greater than the red, to which the heat is in a great measure due. These rays are, however, invisible, and therefore their removal is not perceptible to the eye. In like manner the blue glass transmits the very short waves which affect the photograph, but which are invisible, while it cuts off the red and yellow rays to which the sensitive plate does not respond. If now the light is analyzed by a prism, we shall find that for each color the heat, light, and chemical action are reduced in the same proportion. Thus if the blue glass cuts off nine tenths of the light of the red ray, it will also cut off nine tenths of its heat and nine tenths of its chemical action, and

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the same law holds true for the other colors. While there is this simple relation as regards rays of any one wave-length, it is quite otherwise if we compare the rays of one color with those of another. There is no known method by which we can measure the relative brightness of different colored lights; and while we may compare the temperature of a thermometer exposed first to one ray and then to the other, such a measurement will not properly represent the relative amounts of heat. For we shall find that a different ratio is given by each material forming the surface by which the heat is absorbed. The same difficulty is met with in a photographic plate. So that we have no means of determining the true distribution of radiant energy in the spectrum of any source of light, even if we should eliminate the errors due to absorption by the air, by the glass, or other material through which the beam has to pass, and the unequal dispersion in different portions of the spectrum.

In considering the subject of color or the sensation produced when waves of different lengths fall on the retina, we must recollect that this phenomenon is wholly subjective. Accordingly our knowledge of the aspect of these waves depends wholly on the construction of the eye. Young, in 1802, was the first to show that all the phenomena of color could be accounted for by supposing that the retina contained three kinds of nerves, each sensitive to waves of a certain length, that is, to a particular color. Other colors may be formed by exciting these nerves unequally. Thus a ray of yellow light will excite both the nerves sensitive to red and those sensitive to green, or will produce on the eye the same effect as if red and green rays are received together. In other words, red and green if mixed produce yellow, and not white, as is commonly supposed. The theory of Young was, however, quite forgotten until again brought forward in 1853, when the experiments of Helmholtz and Maxwell added greatly to their probability, and showed that the three

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primary colors, or colors to which the three kinds of nerves are sensitive, are red, green, and dark blue or violet.

In 1837, Sir David Brewster advanced the theory that there were three kinds of rays, physically unlike, which, on entering the eye, produced the sensations of red, yellow, and blue. According to this view, green would be formed by the combination of blue and yellow, while in reality they form white. No popular fallacy has attained a wider circulation than this, and even at the present time the erroneous view is largely maintained. The cause of this error is fully discussed in Chapter III., and it is shown that it is in a great measure due to observations on the mixture of pigments, — a very fallacious method of combining colors.

If, now, we compare these two theories, we shall find them very different. According to Brewster, the cause of the difference of color is objective, that is, outside of the eye, and dependent on the nature of light. Although colors might affect the eyes of different persons or animals so as to produce different sensations in each, yet still every ray might be divided into the same three species, which would be present in all in the same proportion. Again, if in any way we could strike out a particular kind of ray, as red or yellow, the corresponding sensation, whatever it might be, would be wanting in all eyes. According to Young, on the other hand, the impression of color is wholly subjective or dependent on the formation of the particular eye by which it is viewed. As far as the light itself is concerned, the waves of different color are infinitely varied as regards their length, but, as the eye has only three tests for them by its three sets of nerves, our judgment is formed by the relative excitation of these three sets. In other words, according to Young, the three primary colors depend only on the eye, while, according to Brewster, they are inherent in the nature of light. Moreover, each nerve is sensitive, not only to rays of a particular color, but to all of nearly the same wave-length. Thus the red

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nerves are sensitive also to orange, though to a less degree, and even to yellow and green. It is impossible, therefore, to fix the exact hue of the three primary color sensations, but they should be regarded rather as representing certain portions of the spectrum. While, therefore, the simple phenomena of color are largely subjective, or dependent on the construction of the eye, the laws of contrast, either successive or simultaneous, depend wholly on the condition of the retina. They are, in fact, so many illusions to which the artist is subject, and by which he may be deceived unless he is acquainted with the laws governing them. The various relations of colors and how they should be combined are fully discussed in the last chapter of the book, beginning with the simplest two-color decorations, and ending with that highest application of color in art, the oil-painting.

Colors are sometimes divided by artists into primary, secondary, and tertiary, the first term being applied to the colors red, yellow, and blue of the spectrum. The other colors of the spectrum are called secondary or binary, since, according to Brewster's theory, each is composed of two primary colors, while tertiary colors are formed by combining two secondaries. These terms are not used in the present work, since they are based on the erroneous theory that the three elementary color sensations are inherent in the light, and not in the eye. In reality, all the colors of the spectrum are equally primary, being composed of rays of uniform wave-length, and all ordinary colors are formed of rays from every portion of the spectrum, differing only in the proportions in which they are combined.

The greatest confusion exists among various authors in the use of several terms relating to color. Thus *hue*, *tint*, and *shade* are sometimes used promiscuously, while in reality the first term denotes the color or wave-length, while the best authorities apply tint to any color mixed largely with white, and shade to a similar admixture of black. Only the first of

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these three terms is used in the present work. Several adjectives also need to be defined. Colors are said to be *full* when seen in their greatest purity, unmixed with any others, as in the spectrum, and of such a brilliancy as to excite the optic nerve strongly, without dazzling it. If the light is feeble the color is said to be dark; while, if a considerable amount of white is present at the same time, the color is said to be light or pale. In brief, rays of different wave-lengths or colors are said to have different hues. If mixed with a large amount of white, they are said to be pale, and are then called tints. A feeble illumination, or, in the case of pigments, an admixture of black, gives in like manner dark color, or shades. Monochromatic colors, or those unmixed with any others, are said to be full when of moderate brightness. These definitions are more fully discussed on pp. 96–100.

So much has been written on the subject of color by those familiar with the subject only from the standpoint of art, that it was with much satisfaction that we first heard of this work as written by one so well acquainted with the laws of light as Professor Von Bezold. As a result we have here a work based on the rigid laws of modern optical science, instead of the fantastic theories to be expected from persons whose professional success depends largely on the power of their imaginations.

EDWARD C. PICKERING.

INSTITUTE OF TECHNOLOGY, May, 1876.

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DESCRIPTION OF THE PLATES.

PLATE I.

FIG. 1 on this plate shows the spectrum of the light of the sun; Figs. 2 and 3 represent the spectra of gamboge and of Prussian-blue, as they are seen when exceedingly narrow lines painted with these colors on a black ground are looked at through a good prism. These three figures, together with the two others given on the same plate, are intended to show the difference between the mixture of colors and that of pigments, and to demonstrate why the mixture of yellow and blue pigments should produce green, while, if the light reflected by these pigments is allowed to act simultaneously upon the same spot on the retina, the effect produced is white, or rather, owing to the low degree of brightness, gray, which is simply white of reduced luminosity. If the two pigments are mixed upon the palette, one of them absorbs one part of the rays of light, while the other absorbs another part; so that only a very small residue is left. This residue is composed of those rays which both pigments allow to pass; that is to say, in the case under consideration, green, as shown by Fig. 4. If, on the contrary, the light reflected by the pigments is allowed to mix in the eye, the retina receives all the rays emitted by both pigments, as shown in Fig. 5. (See p. 86.) The chromolithographic representation of the various spectra is very good, although, as a matter of course, it is impossible to rival the brilliancy of the spectrum itself, especially in the violet hues.

PLATE II.

This plate shows the color-chart of ten divisions, as described on p. 111. Both figures exhibit the same full colors on the circumference of the circle, but the upper figure contains the gradations from the full through the pale colors, to white, while the lower figure contains the gradations from the full through the dark colors to black.

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The hues and gradations here represented are limited to a definite number. If we conceive all these hues and gradations to pass into each other gradually, we shall obtain a representation of all colors which can be obtained by the mixture of all hues with white on the one hand, and with black on the other. The upper figure will then be the image of the base of the so-called cone of colors (see p. 106), while the lower figure will represent the outer surface of the same cone seen from above. It will be apparent from this that the broken colors are not shown on this plate, as these broken colors are situated within the cone. The hues which are found opposite to one another on a straight line running through the centre of either of these two charts are complementary. All the colors represented on the circumferences of the charts are found in the spectrum, with the exception of purple. This hue is not found in the spectrum, and can only be obtained by superimposing the red and the violet ends of two spectra. The fact that purple is the product of the mixture of red and violet is indicated in the figure by the straight line which connects these two hues.

The hues shown on the plate are not quite correct, as it is impossible to reproduce them with perfect accuracy by means of the printing-press. To arrive at a more correct representation of the color-chart, showing all the transitions from one hue to another, and not limited to any definite number of hues, the following of Dr. Schoenfeld's water-colors might be used to advantage: purple lake, light vermilion, deep chrome, gamboge in a layer of medium thickness, yellow-green vermilion, emerald green with a slight admixture of black, medium permanent green mixed with a small quantity of blue, a mixture of blue oxide and green-blue oxide, and ultramarine. For the violet an aniline color will have to be used, which is not found among artists' colors. The degradation of the hues also leaves something to be desired, especially in the upper figure, in which the effect was sought to be obtained by repeated printings of white; but the result of this has been rather to dull the colors than to increase their brightness. The bluish color of turbid media, which is shown by white when dragged over a dark ground (see p. 76), likewise asserts itself. In spite of these criticisms the plate is nevertheless creditable, in view of the difficulties which had to be overcome.

PLATE III.

The three plates which in their combination form Plate III. would almost appear to need no explanation. They are intended to demonstrate the change which one color may be made to undergo when placed

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in juxtaposition with some other color. When we look at Plate III. *a*, the two red disks appear to be both of the same, or at least very nearly the same hue; but if we turn to Plate III. *b*, upon which the colors of the ground are reversed, the upper disk seems to be much darker and of a deep red; while the lower one, on the contrary, appears much lighter, and acquires a yellowish hue. Finally, if we turn to Plate III. *c*, we shall see both disks in their true relation to each other, uninfluenced by contrast. On III. *a* the difference is diminished, and in a favorable light it may even disappear entirely; by changing the ground, as on III. *b*, the difference is increased. (See p. 167.)

PLATE IV.

This plate shows pairs of colors (see § 94) and triads of colors (see § 97), the hues employed being those of the color-chart of twelve divisions (see § 56). All these pairs and triads form good combinations, and the pairs are composed of those colors which were formerly supposed to be complementary. This is absolutely true, however, of only one pair, purple and green, while for some few of the others it is only approximately true. The pairs are: (1) carmine and bluish green; (2) vermilion and turquoise-blue; (3) orange and ultramarine; (4) purple and green; (5) yellowish green and purplish violet; (6) yellow and bluish violet. The triads are composed of the following colors: (7) carmine, yellowish green, and ultramarine; (8) vermilion, green, and bluish violet; (9) purple, yellow, and turquoise-blue; (10) orange, bluish green, and purplish violet.

In regard to the colors of the chromolithographic reproduction, the reader is referred to the description of Plate II.

PLATE V.

It is the purpose of this plate to show the effect produced upon each other by two colors, when juxtaposed in compartments differing in area, and with or without borders. The plate is printed in three flat tints, red, blue, and black. Nevertheless, the red, if looked at from a distance, will show a tinge of purple in Fig. 3, while in Fig. 4 it has more of a yellowish tinge. Again in the left half of Fig. 5 it appears darker than in the right half, and the same effect is noticed still more strongly in Fig. 6. Figs. 7 and 8 act similarly in regard to the blue, as they likewise produce the impression of three different shades; while Figs. 1 and 2, in consequence of the effective borders which separate the colors, allow the latter to be seen as they would appear upon a neutral field.

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In Figs. 3, 5, 6, 7, and 8 the mixture of the colors asserts itself; Fig. 4 shows the effect of contrast; while in Figs. 1 and 2 both these effects are prevented by the borders. (See pp. 170, 183, 204, 208, and 209.)

PLATES VI.–XI.

These plates are very useful in showing the effect produced upon black figures executed on colored grounds. Such figures are apt to show a slight tinge of the color which is complementary to the ground, so that black figures on a green ground will appear of a reddish black, and so on. This effect will especially be noticed when the plates are so held that the glossy ink of the letters sends reflected light to the eye. But it will be noticed in any position, and much more vividly, as soon as white tissue-paper is laid over the plates, thus showing that an admixture of white light is favorable to the production of contrast. Another point illustrated by Plates VI.–XI. is this, that cold colors are much more powerful in calling forth contrasts than warm colors. The contrasting color can easily be made to appear upon the blue and the green paper; the red paper, on the contrary, presents some difficulty, and in the case of the yellow paper this difficulty is still greater. (See §§ 73 and 74.)

In passing it may be well to apologize for an error which has crept into the text, as the orange plate, mentioned on p. 160, will not be found in the book.

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THE THEORY OF COLOR.

FIRST CHAPTER.

INTRODUCTION. — PHYSICAL BASIS OF THE THEORY OF COLOR. — SPECTRUM.

1. Objective and subjective phenomena.

If we devote special attention to the impressions which we receive through the eye, we shall soon discover that they may be divided into two large groups.

Those of the first group correspond to definite objects of the outer world, and through them we receive our knowledge of the existence of such objects. The impressions of this kind, which are called *objective*, are the cause of the phenomena of sight.

But besides these there are other impressions which cause sensations of light, although there are no objects of the outer world corresponding to them. We frequently perceive phenomena of light and of color, even with closed eyes and in a perfectly dark room. When we fall asleep, for instance, especially under morbid excitement, as in a feverish state, our whole field of vision is filled by luminous forms, which, by incessantly changing and moving about, constantly elude our endeavors to observe them closely. A blow upon the eye, even the quick movement of the eyeball, is sufficient to produce phenomena of light. Very bright, luminous objects, such as the sun or an intense flame, leave images upon the

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eye after we have turned away from them, or after the flame has suddenly been extinguished.

The cause of these phenomena, therefore, must no longer be sought in objects having their position outside of the body, even if the phenomena were *indirectly* called forth by such objects, as in the case of the last illustration, but they owe their origin to the sensitive organism. They are consequently called *subjective* phenomena.

The subjective phenomena of light are generally unwelcome to us. They interfere with the regular, efficient use of the eyes; they give rise to a variety of illusions; and frequently occasion anxiety and discomfort to persons who are not aware of the cause which produced them. Many a ghost-story owes its origin to these subjective phenomena of light, and many a hypochondriac is confirmed in his gloomy thoughts, if by chance his attention is called to them; yet these phenomena may be perceived by all healthy people if they are attentively looked for.

Now, although the second group of phenomena of light and of color might almost appear to be of a very low order of importance to the subject immediately under consideration, we shall nevertheless find, upon closer investigation, that this is not so. For when a surface, which is in itself gray and colorless, suddenly acquires color by being placed in juxtaposition with a colored surface, or when a color is changed by being placed alongside of another, these changes owe their origin but indirectly to an outer cause, and are in reality of a subjective nature.

Hence, all effects of contrast belong to this group of phenomena. And it is universally known of how great an importance these very effects are to the artist.

Generally speaking, the whole realm, the investigation of which we have here undertaken, is of a very complicated nature, as it is situated upon the borders of three distinct sciences.

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In the theory of color the investigator must deal at one time with purely physical facts, that is to say, with facts which are independent of the living organism; then again with physiological processes, that is to say, processes which are entirely peculiar to this organism; and finally there must be added to these the activity of the reasoning faculty, the judgment, and psychological and æsthetic questions.

It will be well to understand clearly beforehand, in each individual case, upon which of the three fields just named we are operating. A passing glance at the processes involved in the act of seeing in general will help us to such a clear understanding.

2. The act of seeing. The transparent media of the eye act upon the light which enters them, in a manner similar to the lenses of the camera employed by the photographer. They produce in the interior of the eye an image of the objects of the outer world. This image, under normal conditions, is projected upon an exceedingly delicate membrane, which is spread out in the inner part of the eye, and is called the *retina*. The latter is composed throughout of nervous elements, most cunningly constructed, each element being connected with the brain by fine nerve-fibres, which together form the so-called *optic nerve*. These elements are excited by the light impinging on them. Consequently, as for each point in the outer world (the field of vision) there is a corresponding point upon the retina, it follows that as many points can be separately perceived as there are separate sensitive nervous elements upon the retina. Should two or more impressions act upon the same element simultaneously, a separate perception of each is no longer possible, and the result will therefore be a combination of the impressions. This is the case, for instance, when we look at a line-engraving from a considerable distance; the black lines with their white intervals are no longer seen, and in their place we perceive evenly graduated tints. A cashmere shawl, under

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similar circumstances, will show mixed colors, instead of separate and variously colored threads.

The processes which a ray of light, or a bundle of such rays, is subjected to, in so far as they take place outside of the eye, are of a purely physical character. The passage of the rays through the transparent media of the eye is likewise regulated simply according to the laws of inanimate nature, and upon the retina of an eye freshly cut from a dead animal the image is produced as sharply and as clearly as upon that of a living eye.

The processes on the retina, on the contrary, are of quite another kind. They are based upon the peculiar activity of the living organism, and their investigation, instead of being a part of the domain of physics, belongs to physiology. It was the insufficient separation of these two domains which proved to be especially fatal to the theory of color. When two pigments are mixed upon the palette, the light emanating from them passes, before it reaches the eye, through a physical process, the laws of which are completely independent of the construction and of the activity of the sensitive organism. If, on the contrary, light of various colors falls simultaneously upon one of the elements of the retina, as in the case of the fine colored threads of the shawl, cited above, the different impressions must be blended into one upon the retina, and it is even possible that the blending does not take place until after these impressions have reached the brain. In fact, the results of the mixture of *pigments*, and those of the mixture of *colors upon the retina*, are quite different from each other, and the transfer to the latter of the results obtained by the mixture of pigments has for a long time essentially impeded the development of the theory of color.

But in *seeing*, there are furthermore associated with these processes of a physical and a physiological nature the activities of the reasoning faculty and of the judgment.

The image of the outer world is formed upon a child's

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retina quite as clearly as upon that of a grown person, and the sensitive elements are the same in both cases; nevertheless, the child reaches out its hands after the sparrow upon the roof, or will even attempt to catch the moon. In the course of time, however, the child, by means of the small differences between the images in the two eyes, which are caused by the difference in the position of each eye in relation to the objects existing outside of it, and by availing itself of various other circumstances, acquires the faculty of judging of distances, and therefore immediately *sees* things in their proper position. We need the aid of the sense of feeling, and the aid of the locomotion of our own body, to develop the conception of space. The experiences gained by these means, together with the simultaneous impressions made upon the eye, are then retained by the memory, and thus the power of judging of the relative positions of the various objects seen is gradually acquired. As a matter of course, these conclusions are mostly arrived at unconsciously, and so quickly, by reason of their frequent application, that they unite into one act with the physical sensation, and take the form of a *perception*. There are other cases, however, in which it is impossible for us immediately to interpret the physical sensation, cases which require that we should look long and attentively, and which may even necessitate the movement of the head or of the body, before we can see or recognize the object. But after we have once observed and understood the impression, a passing glance will be sufficient to recognize it again. What we call a *practised eye* is therefore dependent upon this whetting of our *judgment*, and this fact will explain why a person possessing such a practised eye will immediately perceive things which another person, whose eye, looked upon as an optical instrument, may be vastly superior, does not see at all, or sees only with difficulty.

These explanations will be sufficient to characterize the various departments of science with which we shall have to

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deal, and the various divisions of the work will have to correspond with these several departments.

At first we shall have to direct our attention to the physical basis of the theory of color, or, in other words, to the objective nature of color. This subject will be treated in the first two chapters, which are devoted to the investigation of the origin and the nature of color.

We shall then have to investigate the impressions which are produced in the eye by the various colors, when acting upon it either singly or in groups. To this division belong the theory of the mixture of colors, and the classification of the color-sensations, that is to say, the system of colors, which is closely connected with the theory to which we have just alluded. These subjects form the contents of the third chapter.

In the fourth chapter, on the contrary, which is to treat of contrasts, we shall have to speak principally of the influence exercised upon our judgment of a color, when such color is placed in juxtaposition with others.

In the closing chapter, finally, we shall apply the knowledge acquired to the theory of the combination of colors, that is, to æsthetical questions.

3. Luminous and non-luminous bodies.

The observation of the objective phenomena of light and of color, or, more strictly speaking, the investigation of those bodies which appear luminous and colored, will again lead us to a division into two large groups. There are bodies which are visible as long as no other (opaque) object intervenes between them and the eye of the observer. The sun, the fixed stars, all glowing and burning substances, belong to this class.

On the contrary, there are also other bodies which only become perceptible to the sense of sight when a body of the first group can act upon them, that is, when they are illuminated.

The bodies of the first group are called *self-luminous*, while those of the second group are designated as *non-luminous*, or,

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in as far as they are made visible, *illuminated* bodies. The latter receive the light, through which they affect our eye, from a foreign source, but, when so illuminated, they may also become sources of light for other bodies.

4. The light of the sun; white light. Of all sources of light, the sun is by far the most important. It is the sun which every morning, as if by magic, decks field and forest in a gorgeous array of colors, of which the darkness of night gave no foreboding whatever; it is the sun which supplies the light for the daily task of the laborer, as well as for the activity of the artist. Our next subject of investigation must therefore be the origin of the colors under the influence of the sun; the effect of other sources of light may then be touched upon in passing.

When the sun is high in the heavens it appears to be white, and its light has no definite color, in the true sense of the word, but is also pure white. A plain covered with snow, well-bleached paper or linen, a wall freshly whitewashed, when illuminated by such sunlight, will appear white.

When near the horizon, on the contrary, the sun has a yellowish or reddish appearance; and if its rays fall upon the objects just mentioned, these objects will also partake of this yellowish or reddish color.

For physical investigations the light of the sun, when well up in the heavens, is chosen as the starting-point, and this light is summarily called *white light.*

5. Colors produced by refraction; the prism. When illuminated by such white light, some bodies appear colorless, white, gray, or black, while others again appear colored. But among the phenomena of color produced by white light we shall again immediately recognize two different classes. A cut diamond, a dewdrop in the grass, shows bright colors in the rays of the sun; these colors, however, can only be seen when the observer occupies certain fixed positions in relation to the bodies just named and to the sun. The same is

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true of the falling drops of rain, upon which the colored rainbow will also be displayed only under certain fixed conditions.

Other bodies, which are summarily designated as colored, appear in their proper colors, as soon as sunlight or daylight falls upon them.

In point of fact, the process by which colors are developed in these two cases, under the influence of white light, is different in each case. To gain an insight into the conditions governing these processes, it is indispensably necessary to begin with experiments on the phenomena of color, shown under certain circumstances by bodies which are of themselves colorless and transparent. We must, above all, investigate the process by which the colors are caused in the glittering dewdrop, in the cut diamond, or in cut glass, although it may perhaps at first appear as if this manner of producing color could only be of very subordinate importance to the arts. We shall soon convince ourselves, however, that it is just this group of phenomena which must put us in possession of the key to the whole domain.

For these investigations it is best to use a small three-sided body of very clear glass, with highly polished surfaces, known as a *prism*.

The fundamental experiment with the prism may be conducted in the manner shown in the accompanying drawing (Fig. 1). With the aid of a looking-glass, fixed to the outside of a closely fitting window-shutter, the sunlight is projected in a horizontal direction, through a very narrow vertical slit in the shutter, into an otherwise completely dark room. The narrow band of rays is intercepted on its way by a prism, the edges of which are placed vertically; the prism turns the band of rays aside from its direction, and at the same time separates it into an infinitely large number of colored bands of rays, which, after leaving the prism, are again propagated in a straight line. If these bands fall upon a white

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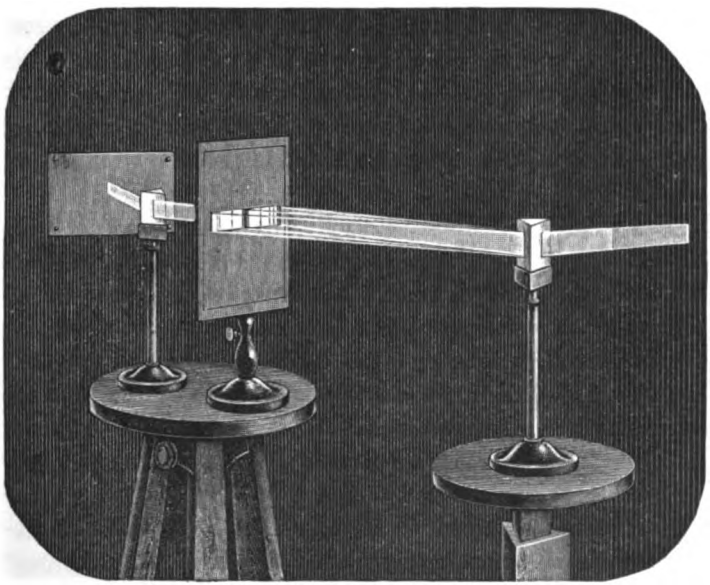
screen, they will produce upon it a brilliantly colored image, known as a *spectrum*. We shall immediately recognize in this image the colors of the rainbow, but of a brilliancy and a clearness far greater than we are accustomed to see in the phenomenon just named. Nearest to the spot upon which

Fig. 1.



the white ray would have fallen, if the prism had not been present, the spectrum is red; this is followed in order by the colors orange, yellow, yellowish green, green, bluish green, turquoise-blue (generally called cyanogen-blue, which is the name given in physics to a blue somewhat tinged with green, and which is best represented, among the pigments used by artists, by the color known as *blue-oxide*), ultramarine, and violet. An attempt has been made to give a representation of this beautiful phenomenon in Fig. 1 of Plate I.; but although this representation is quite perfect in its way, it is

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nevertheless faint and colorless in comparison with the spectrum itself. Even the colors of the rainbow cannot compete in brilliancy and clearness with those of the prismatic spectrum, as in the case of the rainbow the conditions necessary for a complete dispersion of the light of the sun are not as thoroughly fulfilled as in the arrangement just described.

6. The prismatic rays are monochromatic.

If now we cut a narrow vertical slit in the screen upon which the spectrum was produced, a fine bundle of colored rays will penetrate through the slit, provided the screen is in a proper position; and the question now arises: What will be the effect produced, if a prism is again placed in the way of this band of rays?

The result of the experiment is extremely curious. No further dispersion of the colored ray takes place, but the ray is simply turned aside (deflected); on a second screen we shall not see a spectrum, but simply an image of the slit in the first screen, of the same color as that which formerly appeared on this first screen in the place now occupied by the slit. If the slit in the first screen is in the red part of the spectrum, the image of the slit on the second screen will also be red, and so on.

If the second prism be so placed as to form the same angle with the colored ray which the first prism formed with the white ray, the angle in which the colored ray is turned aside from its direction (deflected) by the second refraction will be exactly as great as the angle which the colored ray, upon leaving the first prism, forms with the original white ray.

7. White light is the sum of all the colored rays.

The experiment therefore demonstrates that white light consists of the sum of all the colored rays which we see in the prismatic image.

A rigorous scientific investigation fully confirms this view. From such an investigation it results, that the different colored rays are refracted at the boundary-plane of two trans-

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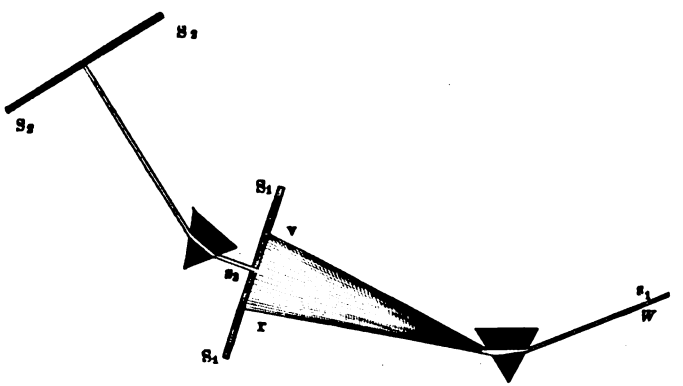
parent bodies, say for example air and glass, according to a law which is similarly constructed for all, but which nevertheless differs somewhat for each color. Red light is less deflected by refraction from its original direction than yellow light, yellow less than green, and so on, while the violet ray is deflected most of all.

Hence, if we conceive such differently colored rays as travelling along the same straight line, they will be compelled to disperse in different directions when falling upon a prism, and thus the colored prismatic image is produced.

The process which here takes place is conventionally represented in Fig. 2. *W* denotes the window-shutter, s_1 the

Fig. 2.



first, s_2 the second slit, S_1 the first, S_2 the second screen; *r* denotes the red rays of the spectrum, *v* the violet rays at the opposite end; and all the rays lying between these two are represented by thinner or thicker lines, according to the degree of brightness which they possess in the prismatic spectrum. The first screen is so placed as to allow the green light to pass through it.

This experiment on the dispersion of white light by means of the prism was made in the year 1672 by the great English mathematician, ISAAC NEWTON. It will for all time to

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come remain the starting-point for the theory of color, in spite of the attacks made by GÖTHE upon this very experiment, which, nevertheless, he did not consider it worth while conscientiously to repeat.

Newton's fundamental experiment demonstrates that the colored rays obtained by means of the prism are not capable of further dispersion, at least not by the same means. Nor have all the experiments, which have since then been made in immense variety in the department of optics, brought to our knowledge a means by which such further dispersion of a prismatic ray is made possible.

The view confirmed by this experiment — namely, that a white ray of light is composed of an infinite number of colored rays — has at first sight something very improbable. But it loses its strangeness as soon as we have made ourselves familiar with the conception of the nature of light, which modern physical science has shown to be the only true and tenable conception.

8. Light is a wave-motion. The most varied experiments and profound theoretical investigations, which again were proved and confirmed by experiments step by step, compel us to form a conception of the nature of light similar to that which we have already had for a long time of the nature of sound.

By these investigations it has been demonstrated that the sensation of light is produced by the vibrations of the so-called *ether* (not to be confounded with the substance known to chemistry under the same name), a medium which fills the whole space of the universe, and penetrates all bodies. These vibrations are propagated with an exceedingly great velocity in space and in transparent bodies, and are thus the cause of the origin of so-called wave-motions. A good representation of such wave-motions is given by the circles produced by a stone thrown into the water, or perhaps still better by the beautiful undulatory motion which may be observed when

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the wind sweeps over a field of ripening corn. In the one case the particles of water, in the other the ears of corn, execute, *one after the other*, the same or a similar swinging movement; and this vibration is called wave-motion. But very different kinds of such wave-motions may be propagated simultaneously through the same medium, without essentially interfering with one another. If, for example, we throw two stones into the water at a short distance from each other, each of them will produce its circles, and we can without difficulty follow the course of the waves of these circles even in those places where they overlap one another.

The multitudinous systems of waves produced by the instruments of a full orchestra are propagated without impediment, not only through the air, but even through the narrow acoustic duct of the ear; and a practised ear is capable not only of following each part, but even the playing of each single instrument, in a brilliant symphony.

In reality each individual particle of air naturally makes only one motion in any one moment of time; but this motion is qualified by all the separate motions which act upon such a particle, and by suitable apparatus these compound motions can again be resolved into their elements. We have such an apparatus for the waves of sound in the human ear, for the waves of light in the prism. The ear or the prism separate the waves of air or of ether, which impinge on them, into waves, the vibrations of which take place in accordance with a simple law, and in a manner similar to the vibrations of the pendulum. Between such simple vibrations there cannot be more than two points of difference; they can differ, on the one hand, in the time which passes while one vibration is executed, and, on the other hand, in the distance which is travelled over by one of the particles in motion while making one vibration.

The *time* necessary for the completion of one vibration is called the *period of vibration*. Upon the length of this period

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depends, in acoustics, the *pitch* of the sound, in a musical sense; in optics, the *hue of the color.*

The *length of path travelled over*, or, what is the same, the *greatest distance from the point of equilibrium* reached by the particle during one vibration, that is to say, the amplitude, determines in the one case the *intensity* of the sound, in the other the *brightness* of the ray of light.

In the ray which emerges from the prism, the vibrations are executed according to the simple law just alluded to, and the differences between the variously colored rays arise only from the difference in the length of the period of vibration. But the duration of this period in the vibrations of light is exceedingly minute. The impression of red light caused by one end of the spectrum is produced by vibrations of which 400 trillions are executed in one second, while as many as 790 trillions of vibrations correspond to the violet end of the spectrum. The numbers of the vibrations corresponding to all the other rays, which lie between these two ends of the spectrum, will also be found to lie between the two numbers just mentioned.

It may appear hazardous to undertake to speak of such numbers, but nevertheless their correctness can be affirmed with the greatest safety. These numbers have been determined in a great variety of ways, by methods totally different from each other, and the results arrived at have always been the same. It may be that the still more exact determination of some of the quantities which must here be considered will necessitate small corrections of all these numbers; but at the worst these corrections can amount only to small fractions of the sum total, and as they will have to be applied equally to all the numbers in question, the relative proportions of the latter will not be changed by them.

From this digression — undertaken only for the purpose of doing away with the improbability attaching to the conception of the nature of white light, which Newton's funda-

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mental experiment *compels* us to form — we will now return to the experiments with the prism.

9. Different methods for the investigation of spectra. The method above described for the production of the prismatic image yields a better and more beautiful result than any other, especially if suitable glass-lenses are introduced, which have been omitted in the figure so as not to divert the attention from essential to unessential points. Unfortunately this method presupposes contrivances and apparatus of a somewhat costly nature. The slit in the shutter must be formed by finely polished and exactly parallel metal edges, the prisms must be cut with the utmost care from the very clearest glass, best of all flint-glass, which is made only with difficulty, and the setting-up of the apparatus must combine great solidity and firmness with the possibility of delicate adjustment.[1]

Fortunately, however, a simpler arrangement will likewise be sufficient to produce at least a tolerable image of the spectrum, and to execute those experiments which are of most importance for our purposes. For we may simply observe the slit in the shutter through a prism, or we may even do away with the slit entirely, and may simply replace it by a tightly stretched thread, or even by a narrow strip of paper, upon a black ground, — best of all upon black velvet, — and we can then observe these objects through a prism.

Figs. 3 and 4 give an idea of these methods of observation, a prism placed vertically being employed in the one case, while in the other the position of the prism is horizontal. Fig. 3 shows at the same time where the colored image must be looked for, as the eye must not be directed towards the strip, if we desire to see the spectrum corresponding to it.

The physical process with which we have to deal in this experiment is explained by Fig. 5.

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Fig. 3.

The rays proceeding from the white strip (or the slit) *s* fall upon the prism, and are there differently deflected according to their color. The red rays, after they have been refracted, travel in a direction as if they had proceeded from the point *r*, the violet rays as if they had proceeded from *v*. All the colored rays situated between red and violet will appear as if proceeding from points between *r* and *v*, on the line *r v*. The spectrum will therefore be seen in *r v*.

Fig. 4.

This method of simply observing a bright strip, or a slit,

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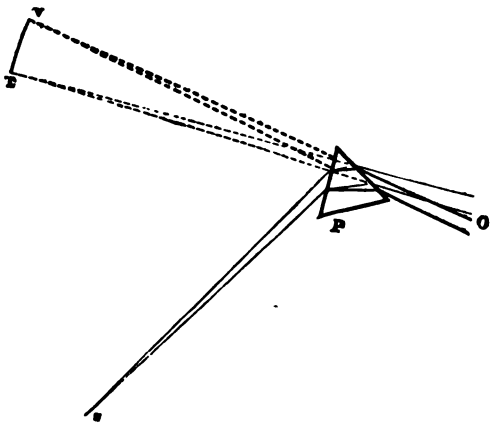
Fig. 5.



through a prism, may be extraordinarily perfected by the introduction of glass-lenses (telescopes), so that the spectra thus produced leave nothing to be desired in regard to clearness and beauty. In most scientific investigations of spectra, instruments of this kind (spectroscopes) are almost exclusively used, as all the necessary pieces can be combined in a single apparatus of very moderate dimensions.

After this somewhat dry, but unfortunately unavoidable, explanation of the methods employed in the production of the spectrum, we must now devote somewhat closer attention to this colored image itself.

10. The solar spectrum. If we look from a long distance at the spectrum produced upon the screen, or if we diminish the distance between the prism and the screen, so as to reduce the extent of the spectrum to very small dimensions, we shall see only three or four colors, namely, red, green, and violet, or perhaps red, blue, and violet. If we place ourselves near to the screen, or if we increase the extent of the spectrum, we shall presently discover a very narrow line of yellow between the red and the green, while between the colors already named we shall in addition observe all pos-

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sible transitions, which we may again conceive of as individual colors, and which we can designate by special names.

There used to be great uncertainty in regard to the division of the spectrum into different colors, or at least into different regions; and on account of the gradual transitions, it is indeed impossible to say with certainty where the green ends and the blue commences, etc. We shall therefore be always compelled to accept a conventional standard in designating the color of a certain place in the spectrum. But where shall we find the starting-point for such a standard?

It is inadmissible to measure the breadth of the spectrum, and then to divide it with the aid of a measuring-rod, for this breadth is dependent upon a variety of secondary circumstances, and, even if this were not the case, it can never be determined with accuracy; for neither at the red nor at the violet end is the spectrum sharply defined, but at both ends it passes gradually into darkness. Furthermore, it is possible, by shading off the bright parts of the spectrum, to lengthen out the latter very materially, especially at the violet end.

Again, the colors of the spectrum can only be very imperfectly imitated by pigments, and thus the difficulty of arriving at a mutual understanding in regard to definite places in the spectrum was very keenly felt for a long time.

After making a variety of experiments, the celebrated optician FRAUNHOFER finally succeeded, in the year 1814, in remedying this evil by a discovery, the far-reaching importance of which he foresaw with an eye truly prophetic.

It was left to the two German investigators, KIRCHHOFF and BUNSEN, to draw the conclusions of this discovery forty-six years later, and to forge from it one of the most potent weapons of human investigation, in the shape of *spectrum analysis*.

By means of the development which Fraunhofer's discovery received at the hands of the investigators named, we

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are now enabled to examine into the chemical constitution of the most distant heavenly bodies, and to observe processes taking place upon them which, only two decades ago, we were compelled to believe would remain forever hidden from the human eye.

The discovery by Fraunhofer, here alluded to, consisted in this, that in spectra produced by him with the greatest care, he observed a large number of fine black lines running parallel to the slit. Among these lines, which are counted by thousands, there are certain ones so distinguished by depth of blackness, or by peculiar grouping, that they are easily retained by the memory.

These lines are now employed as unmistakable landmarks, and to make them more generally available for this purpose the most important were already designated by *capital* letters by Fraunhofer himself, while some of those of less importance were designated by *small* letters. These designations have been universally adopted, and the lines themselves are called the *Fraunhofer lines*, from their discoverer. The most important of them will be found marked in Fig. 1 of Plate I.

The use of these lines therefore obviates the necessity, in scientific investigations, of designating certain places in the spectrum by their colors, which it is but too frequently quite difficult to describe, and enables us to characterize such places by simply referring to the nearest Fraunhofer lines.

Unfortunately, however, the exclusive use of these convenient aids is inadmissible for our purposes, and it will consequently be indispensable to come to an understanding as to the designation of the colors of the spectrum by the names of pigments. But even here the Fraunhofer lines will do substantial service in the investigation of the real spectrum itself, as well as in that of its pictorial representations.

11. The colors of the spectrum. In attempting to arrive at such an understanding, the fact already alluded to, that the colors

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of the spectrum in general can be only very imperfectly imitated by pigments, makes itself felt quite unpleasantly; and it is owing to this fact that the names adopted by physicists differ in part from those employed by artists, and still more so from those by which the colors are sometimes designated in the art-industries.

We must of course adhere to the nomenclature of physical science in our discussions, making use of the terms adopted by HELMHOLTZ, which are now universally received; and from this rule we shall only deviate in two instances, to avoid the possibility of error. The names of pigments used in painting must always be understood as referring to the water-colors made and sold under these names by Dr. Fr. Schönfeld & Co., of Düsseldorf, unless the contrary is especially stated.

After these preliminaries we can now enter upon a more detailed examination of the colors of the spectrum.

The color of the least refrangible end of the spectrum, up to the line *C*, is called *Red*. It begins with dark brownish red, and passes through an exceedingly fiery red into the color of vermilion. The fiery red of the spectrum is best represented by carmine in the form of powder. In oil-colors it may be imitated by glazing with madder-lake on a ground of cadmium-yellow.

The red is followed by *Orange*. The orange, in its more reddish modifications, corresponds to red-lead, which is used in water-color painting, while as an oil-color it is only employed by house-painters, more especially, and in very large quantities, as a ground in painting iron. Towards the line *D* the orange passes into a very bright golden yellow, which might perhaps be imitated by cadmium-yellow.

Close to the line *D* follows a very narrow band of pure *Yellow*. The tint corresponds to "light chrome-yellow." This is the *brightest* spot in the spectrum, and at the same time the spot which shows the quickest transition in the hue

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of the color. The yellow extends to about one third of the distance between the two lines *D* and *E*.

The second third of the space between *D* and *E* is *Yellowish Green*, corresponding to the color of what is known as "yellowish-green vermilion"; while the last third, as well as the space between *E* and *b*, is of a bright *Green*. The pure green finds its representative, among the finer colors used by artists, in the "emerald-green," which must not, however, be confounded with the "vert émeraude," which latter is in fact a bluish green. Among common colors the well-known poisonous "Paris-green" is an excellent representative of the green of the spectrum.

The green is followed, from *b* to *F*, by *Bluish Green*, which is best represented by vertigris, the patina of old bronzes, or, in want of something better, by medium or deep permanent green.

The bluish green again is followed, in the neighborhood of *F*, by a beautiful blue, which has been named by HELMHOLTZ *Cyanogen Blue*, but which we will rather name *Turquoise Blue*, as the color of the turquoise comes nearer to this blue than the color of any other body known to us, and as the term *Cyanogen Blue* is totally unknown in the artistic and art-industrial sphere. This is the color shown by large masses of very pure water, as for example by the lakes which are fed by the glaciers of the Alps; above all, by the Achensee in the Tyrol, or Lake Garda in Upper Italy, or which may sometimes be seen, under favorable circumstances, in the glacier-ice itself. Among pigments blue-oxide comes nearest to it. Similar shades may also be obtained by glazing with Prussian-blue on a white ground. Weak solutions of sulphate of copper (blue vitriol) likewise show this color. The extent of the turquoise-blue is rather limited, and at the same time it varies considerably, according to the degree of brightness of the whole spectrum. We shall not go far astray, if, with a mean degree of brightness, we place its

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limit towards the end of the first third of the space bounded by *F* and *G*.

The blue which extends from here to near the line *G* used to be called *Indigo Blue* in physics up to the present; but as it is in fact perfectly impossible to imitate it by indigo, while it can be rendered by ultramarine, we shall here designate it as *Ultramarine Blue*. The author is exceedingly loath to change names which have been generally received, as such changes are quite apt to lead to misunderstandings; still, he believes it to be necessary in cases in which the usual designation will be certain to give an erroneous idea, and therefore to cause a still greater number of misunderstandings.

Somewhat before the line *G* the ultramarine passes very decidedly into *Violet*. With this color the spectrum reaches its end, as it gradually passes into darkness, and at the same time fades out beyond the two broad lines *H*. If we carefully cover up by screens, or shade off, all that part of the spectrum which has so far been investigated, we shall find that the spectrum still extends far beyond these lines; but it is impossible to recognize any color in this extension, all that can be observed being a very faint glimmer, to which the name of "lavender tint" has been given.

The violet of the spectrum has no good representative among the artist's colors. Among dyestuffs, on the contrary, it is all the better represented, as the combinations of aniline, especially upon silk, yield magnificent violet hues.

Under ordinary circumstances the visible spectrum ends with the violet, and consists therefore of *red, orange, yellow, yellowish green, green, bluish green, turquoise-blue, ultramarine-blue, and violet.*

In using these names henceforth, without any further qualification, it is always understood that they are to designate the colors of the spectrum according to the detailed definitions just given.

Glancing at the spaces occupied by the individual colors in

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the spectrum, we shall at once observe with surprise that the various hues are proportionately crowded together much more at the red end than at the violet end. This fact is not based upon the nature of the phenomenon of color in itself, but it is a special peculiarity of the prismatic spectrum. It is possible completely to decompose white light into its component parts by other means, that is to say, to produce spectra which show the Fraunhofer lines exceedingly well without the aid of prisms; and in such spectra, called spectra by interference or by diffraction, the succession of colors is precisely the same as in the prismatic image, but the spaces allotted to the individual colors are different. The colors at the red end are here drawn asunder, while at the violet end they are pushed together.

12. Influence of brightness on the spectrum.

But even without regard to these distortions, which are shown in either case by one of the two ends of the spectrum, the spaces allotted to each individual color are still very different in extent. Thus the yellow and the turquoise-blue occupy proportionately small spaces in both kinds of spectra, and the part which they play in general is indeed quite peculiar.

If, for instance, we produce spectra of very different degrees of brightness, we shall find that the hues (or colors) suffer remarkable changes, and that at the same time their limits, so far as they can be defined, are shifted. And this changing in hues and shifting of limits is conspicuous above all in the yellow and in the turquoise-blue.

If the brightness of the spectrum is reduced, the yellow disappears almost completely, while the red spreads itself out farther towards the green side, so that the line *D*, which before formed the boundary-line between orange and yellow, is at first entirely surrounded by orange, and finally by a dirty hue of red-lead. At the same time the green is extended towards the violet, so that the line *F* is situated in the bluish green, while the turquoise-blue disappears entirely, and the

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space occupied by the ultramarine is also contracted more and more.

Under these circumstances the whole of the spectrum shows only a brownish red, green, and a violet of a very low degree of luminosity, a tint which might indeed be justly called indigo. If we proceed still further in the diminution of brightness, the violet end will be the first to become invisible, while the red diminishes greatly in luminosity, the piece between *D* and *E* being the only one which remains recognizable in a faint greenish hue. Finally this hue likewise disappears, and the Fraunhofer lines alone are left, relieved in black from a faintly whitish ground. Between the lines *D* and *E*, however, the spectrum, with all its lines, still remains visible for some length of time, even after all traces of a sensation of color have long ago ceased, provided the room be completely darkened, and the eye accustomed to darkness.

To study these phenomena the spectrum may either be objectively represented upon a screen, or it may be observed in the spectroscope, as in both cases the process is identically the same.

It will become evident, further on, that these changes in the sensation of color, caused by decreasing luminosity, are of importance to the theory. For the present they are also of interest to us, because they explain the peculiarities of moonlight.

13. The light of the moon. When the moon is near the horizon, its light is yellow; when it is high in the heavens, its light is white, as in the case of the sun; and the spectrum of the moon differs from that of the sun merely in the lower degree of its luminosity. It shows the same colors and the same lines, as it is indeed nothing but reflected sunlight. But it is just this incomparably lower degree of luminosity — the light of the sun is about 500,000 times stronger than that of the full moon — which causes the com-

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plete change in the effect, or, more correctly speaking, in the sensation produced by the various colors.

We notice by moonlight only those faint hues of color which we observe in the spectrum when it fades gradually away. White surfaces show the same dull greenish hue which is longest perceived in the spectrum; a roof covered with red brick tiles appears dark brown, perhaps still somewhat of a reddish brown; and as long as the sun, from below the horizon, continues to add a small contribution to the illumination, we may also observe, especially in the sky, deep dark blue hues, with a slight inclination towards violet.

14. The limits of the spectrum; invisible rays. We have just seen that the spectrum, as it decreases in brightness, is narrowed in from both sides. But might it not also be possible to extend it beyond its usual limits? Are those vibrations the only ones propagated through the ether, the periods of oscillation of which lie between the limits above stated, or is our eye incapable of receiving a sensation from any others? If the latter proposition be true, the case will resemble that of the spectrum of a very low degree of luminosity, in which we see only the rays from the middle region.

These questions must be briefly examined before we proceed.

The rays of the sun do not act upon the eye alone; the effect produced in the eye is always coupled with other effects. For the sun's rays also produce heat and induce chemical changes.

Examining the spectrum with a view to these effects, we shall be led to very curious results. A thermometer which is passed through the fan of colors emerging from the prism does not, as might perhaps be expected, reach its highest point at the place where we see the brightest light, but, on the contrary, somewhat outside of the red rays, at a place where we see no light at all. It can also be demonstrated

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why these rays, the existence of which is unequivocally betrayed by the thermometer, are not visible.

Actual experiment will show that some bodies which allow the visible rays of the sun to pass through them without hindrance, and which therefore appear colorless or transparent, act very differently towards the invisible rays. Water, for instance, is almost impenetrable to the rays which are observable beyond the red end of the spectrum by their effect upon the thermometer; glass transmits the same rays badly; while rock-salt allows them to pass very freely; and thus it happens that in a spectrum, the rays of which have previously been passed through water, the action of heat commences only after the thermometer has been introduced into the visible spectrum.

But the media of the eye act precisely like water. If we allow the light, which is to form the spectrum, to pass through the media of the eye of a freshly killed animal before entering the prism, the rays of which we have just spoken will be found to be completely wanting, and the effect of heat in a spectrum so produced will likewise be noticeable only after the thermometer has been introduced into the visible spectrum.

It follows that the media of the eye are impervious to the light of the rays having their place in the spectrum outside of the red, and these rays will therefore never be able to excite a sensation of light, even if the nervous apparatus of the retina were accessible to such a sensation.

The action of the violet end of the spectrum is very similar to that of the red end.

It has already been pointed out above that, after carefully shading off all the visible rays, we may still see the spectrum elongated far beyond the violet end, although without any namable color. The existence of these rays — called the "ultra-violet," from their position in relation to the spectrum, while those at the other end are designated as the "ultra-

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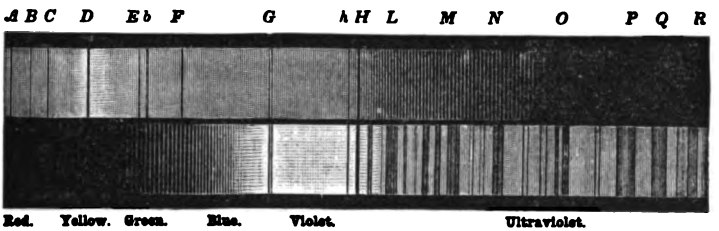
red" — can, however, be demonstrated by still another method, which is of especial importance to us.

15. The photographic spectrum. If the spectrum, instead of being projected upon a white screen, is projected upon a photographically prepared sensitive plate, for the purpose of producing a fixed image, and if, to guard against all error, we mark one of the Fraunhofer lines upon this plate, we shall arrive at a most remarkable result.

For, after the usual photographic operations have been completed, we shall indeed find a spectrum upon the plate; but instead of the spectrum which presents itself to the eye upon the screen, we shall see a spectrum considerably shortened at the red end, and very materially elongated at the violet end.

Fig. 6 gives a representation of both the spectra, one above the other, the upper being the visible, the lower the photographic spectrum. But we must here remark that the photographic spectrum, as regards its extent, as well as the relative brightness of its parts, gives somewhat different results according to the chemicals that have been used. Iodide of silver gives a spectrum different from that produced by

Fig. 6.



bromide or chloride of silver, and with a mixture of these the result again differs. Thus, with a mixture of iodide and bromide of silver the shortening of the red end is not as considerable as when either of these preparations is employed alone.

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Comparing the two spectra represented in Fig. 6 somewhat more attentively with each other, we shall see that those rays which appear brightest to our eye, that is to say, the yellow rays, make no perceptible impression upon the photographic plate, while a multitude of rays, which under ordinary circumstances we cannot see at all, affect the sensitive plate quite strongly.

The latter fact can be illustrated by a very beautiful experiment. If we write upon white paper with a solution of sulphate of quinine, the writing will be perfectly invisible in ordinary daylight. But if we make a photograph of the sheet of paper, the writing will show plainly upon the photographic reproduction, so that in this case we can justly speak of a "photograph of the invisible."

The peculiarity of the yellow rays, above alluded to, explains why rooms in which photographic plates are prepared are provided with yellow windows; and it is due to the same cause that blue and violet dresses, which may appear very dark to the eye, look light in photographs, while everything that is red and yellow usually looks dark. It may even happen that two tints, which appear to us to be perfectly alike, are nevertheless rendered differently by the photographic image.

It is, however, quite impossible to tell beforehand, and without careful investigation, what the photographic effect of any given pigment may be. For it will not do to conclude at first sight that the particular color, which to the eye appears to dominate, is really represented more strongly than any other in the light reflected by the pigment under consideration. This is the reason why many pigments seem to make such curious exceptions to the rule just stated, this rule being that the photographic effect of red and yellow is weak, while that of blue and violet is powerful. Naples-yellow and light ochre, for instance, do not photograph nearly as dark as chrome-yellow, which to the eye is very similar

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to both. Cobalt-blue and ultramarine are rendered almost white in the photographic reproduction. Prussian-blue and indigo, on the contrary, appear dark, but still not nearly as black as chrome-yellow, which, to our eye, is many times lighter. (See p. 89.)

Photographs from paintings therefore frequently show effects of light which are totally false, especially if the original is painted in what is called a warm tone. Looking at a painting through a blue glass may sometimes aid us in determining whether it is suited to photographic reproduction or not. The better the painting remains in keeping, the better will it be fitted to be multiplied by the photographic process.

16. Calorific and chemical action of light. What, then, is the cause of this difference in the effect produced by the various regions of the spectrum?

Until of late it was supposed that the nature of the effect of a simple prismatic (monochromatic) ray depended upon its refrangibility alone, and the whole of the rays were therefore divided into *warmth-giving* (calorific), *luminous*, and *chemically active* (actinic) rays.

This division, however, does not appear to be able to stand the test of the latest discoveries, for it seems probable that the effect of a ray depends essentially on the body upon which it falls.

The reason why the rays reaching beyond the red end of the prismatic image cannot be visible has already been shown. But perhaps this reason is not the only one; it may be that it is not only difficult for these rays to penetrate the media of the eye, but that the retina is itself insensible to them. This is true at least of the violet end of the spectrum.

For if we experiment upon this end with the eye of an animal, as above described in the case of the ultra-red rays, employing, however, a photographic plate as a means of testing, instead of a thermometer, it will be found that the ultra-violet rays can indeed penetrate the media of the eye,

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although they are somewhat exhausted in the process. The reason for their invisibility must therefore be sought in the fact, that the nervous elements of the retina are insensible to these rays, precisely as our ear can only perceive sounds within certain definite limits, while it is impossible to hear higher or lower sounds, although there is no doubt of their existence.

It is easy to see, therefore, why all the rays of the sun are not visible. But why should not all of them be able to produce heat, and to induce chemical decomposition ?

According to the investigations previously alluded to, light consists of the vibrations of the ether, and the same is true of the invisible rays, according to thermometric and photographic experiments.

On the other hand it is supposed that, in the case of ponderable bodies, the phenomena of heat are produced by the vibrations of their smallest particles.

Now we can imagine that the vibrations of the ether may be transferred to the particles of bodies, just as the motion of one body can be transferred to another; as, for instance, in the case of falling water, which, by the aid of a water-wheel, puts in motion the mill-stones, because it transfers some of its own motion to the wheel, which again transmits it to the stones, while behind the wheel the water runs so much slower by reason of this transfer. We can very readily conceive that light, or the vibrations of ether, should disappear, and heat appear in their stead.

This conception receives material support from the fact that those bodies really attain the greatest degree of heat, under the influence of the sun, which destroy or absorb more light than any others, that is to say, black bodies, while white bodies, which, comparatively speaking, reflect the most light, show at the same time the lowest degree of heat.

That the generation of heat is on the whole greatest in the red and ultra-red rays is simply due to the peculiarity of the

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prismatic spectrum. For in such a spectrum the red and the ultra-red rays are crowded together more than any of the others, whence it follows that an object introduced into them is exposed to more rays than in any other part of the spectrum. In the spectrum by diffraction, on the contrary, the maximum of heat corresponds tolerably well with the maximum of luminosity. And it has even been shown of late (by BUDDE), that chlorine gas, which powerfully absorbs the more refrangible rays, acquires a considerable degree of warmth under their influence, although it had been maintained that these rays were totally incapable of generating heat.

These observations therefore compel us to conclude that heat can always be generated whenever any of the rays of the spectrum are destroyed by any body, and, hence, that the action of this body, under the conditions given, will be the essential point to be considered. In such a case, however, it is not at all absolutely necessary that *all* the ether-vibrations which are destroyed, that is to say, all the light which has disappeared, should be transformed into heat, for it may just as well be applied to other purposes.

The example of the mill will again aid us in finding a correct answer. If the stones are allowed to run without any grain between them, they will be heated to an extraordinary degree; but as soon as the corn is introduced, the heat will decrease, and not alone on account of the wetting, which, even in the latter case, is still necessary. The reason is this: In the first instance, the larger part of the motion which the wheel took away from the water, and transmitted to the stones, must be transformed into heat; in the second, a part of this motion is made use of to crush the grain.

Motion, therefore, can also be employed to separate the particles of a body, and perhaps it can likewise be used to induce chemical decomposition. The chemist observes in innumerable cases that heat is capable of producing this result, while photographic experiments and the processes of plant-

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life teach us that light, even without a corresponding generation of heat, has the same faculty.

It is impossible to decide beforehand whether a given ray will act as a calorific or as a chemical ray; but this much is certain, according to the (mechanical) conception just developed, that a ray which is destroyed or absorbed by any body must produce one of these two effects, if it does not produce both of them simultaneously.

That in such a case even red light can produce a chemical effect has been shown only quite lately. It has long been known that plants, if they are to thrive, must have heat as well as light, and that the chemical effect of light plays an essential part in the life of plants. According to the views formerly held, which attributed the power of producing chemical effects to certain rays only, it was also believed that only the most refrangible rays, that is to say, the blue, violet, and ultra-violet, were capable of exercising this influence upon plants.

More exact investigations have shown these views to be erroneous. By exposing plants, or parts of plants, to the exclusive influence of certain prismatic rays, or by allowing the light which fell upon them to pass through colored glass or colored solutions, which permitted only certain groups of rays to act upon the plants, the following propositions were arrived at: —

The chemical processes in plants, as far as they are dependent upon light, are principally caused by the rays of medium and of lower refrangibility. The development of the green color of the chlorophyl (the green coloring-matter of the leaves), the decomposition of carbonic acid, as well as the formation of starch (amylum), etc., in the grains of the chlorophyl, are induced by the red, orange, yellow, and green rays.

The strongly refrangible rays, on the contrary, that is to say, the blue, violet, and ultra-violet rays, are principally or solely

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the cause of the mechanical changes, as far as they are effected by light. They influence the rapidity of growth, compel the so-called zoöspores to move in certain directions, change the tension of the tissues in the organs of motion of many leaves, thereby altering their position, etc., etc.

The proof that other rays besides the most refrangible can also produce chemical effects is of great importance to photography. It justifies the expectation that at some future time we shall succeed in doing away, by the choice of suitable chemicals, with the discrepancy now still existing between the visible and the photographic spectrum, and, as a consequence, between the original and the photograph. At the same time the theoretical speculations just developed may serve as hints in regard to the points of view which will have to be adhered to in making experiments aiming at the solution of this question.

17. Modifications of the photographic spectrum.

At the time when the author wrote down these last lines, now something like two years ago, he gave a detailed statement of the views just developed, in a conversation with a young physicist. He emphasized, above all, that it would be very interesting to test by experiment whether it would be possible, by the admixture of colored substances, to make the photographic preparations sensitive to those rays, which so far had been found to be ineffective. In the following chapter we shall see that pigments possess the peculiar faculty of apparently destroying certain groups of rays, or, to employ the usual expression, of absorbing them. The idea was therefore quite natural, that the light which disappears in such cases might be able to produce chemical effects, in so far as it is not exclusively employed in the generation of heat.

A treatise which appeared a few months after this conversation, when the German edition of this book was already in press, showed how correct these conjectures had been.

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PROFESSOR H. VOGEL, author of an excellent work on photography, has published a series of highly interesting investigations, in which he was evidently guided by views similar to those above enunciated, and which led to very beautiful results. Of these latter, we will single out only one, by way of example. Naphtaline-red is a substance which, in a weak solution, powerfully absorbs the yellow rays; in a more concentrated solution it absorbs also the green, together with the ultramarine-blue and the violet rays, while it permits the red and part of the blue to pass through without hindrance.

A photographic plate, prepared with this substance and with bromide of silver, was decidedly affected by the same yellow light, which is so powerfully absorbed by naphtaline-red, and, with a suitable concentration of the color, Professor Vogel even succeeded in photographing the spectrum from the line *B* in the red to the violet. By adding a small quantity of aldehyde-green to the naphtaline-red, these limits were moved still farther apart. Experiments with various other pigments gave similar results.

It must be mentioned, however, that in these experiments it is not only the absorptive power of the pigments which must be considered, but that the latter must likewise be of a nature which will assist the peculiar photographic process, or, in other words, the metallic reduction of the silver.

Although the details of these processes are in part still enveloped in darkness, they nevertheless prove beyond doubt that the old division into chemically active and inactive rays lacks all intrinsic evidence, and that it owes its origin to the peculiar action of the sensitive substances usually employed.

We may therefore confidently hope that the time is not too far distant in which we shall succeed in removing the greatest defect still adhering to photography, that is to say, the unequal reproduction of the various colors.

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SECOND CHAPTER.

INHERENT COLORS. — COLORING MATTER. — BODY COLORS. — TRANSPARENT COLORS. — VARNISH. — OPTICAL PROPERTIES OF WOVEN FABRICS. — CHLOROPHYL. — THE COLOR OF WATER AND OF THE SKY.

18. Inherent colors. THE experiments thus far made have shown that white light can be resolved, by the aid of the prism, into colored rays of extraordinary beauty. But this manner of producing colors, however great its theoretical importance may be, is practically of but little value, and the arts must therefore use other means for imparting color to the objects with which they are concerned. For this purpose it is necessary to employ substances which, under ordinary circumstances, show always the same color, so that the latter is looked upon as their characteristic peculiarity; and these substances are fastened in various ways upon the objects to which their color is to be imparted.

Such substances are called *coloring matter*, *pigments*, or simply *colors*, which latter designation, however, we must be very careful to avoid in our discussions.

But although pigments, as well as other bodies which are ordinarily called colored, usually show the same color under ordinary effects of light, so that we simply designate them as red, green, blue, etc., we shall nevertheless soon find that the color of such bodies changes with the nature of the light to

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which they are exposed, and that the appearance of very many of them is quite different in the evening from that which they present during the day.

The question now arises: How are the colors of such bodies or substances, the so-called *inherent colors*, produced, and how can their dependence upon the light which illuminates them be explained?

This problem can also be solved quickly and trustworthily by means of an investigation with the prism. The simplest manner of conducting the experiment will be to employ a piece of colored glass, or a clear colored solution.

19. Colored glass. If, for example, we place a piece of red glass (flashed glass, colored with the protoxide of copper) before the slit in the shutter, the light entering the room will be red instead of white, and in a spectrum produced by this light we shall see only red and orange, while all other colors will be wanting.

The red and the orange have retained their position and their extent without change, of which fact we can best convince ourselves, if we cover up only one half of the slit with the red piece of glass; in this case the perfect spectrum of white light will appear immediately above that produced by the light which has been colored red by the glass, and we can see at once that the other colors have simply disappeared.

This experiment admits of two conceptions regarding the effect produced by the red glass. The latter must either have destroyed, kept back, or absorbed all the rays of the impinging light, with the exception of the red and the orange, or it must have transformed all the other hues into the two just mentioned. A further experiment will decide which of these two conceptions is the correct one.

Having projected a solar spectrum upon the screen in the usual manner, we will take a narrow strip of the same red glass which served for the former experiment, and will move

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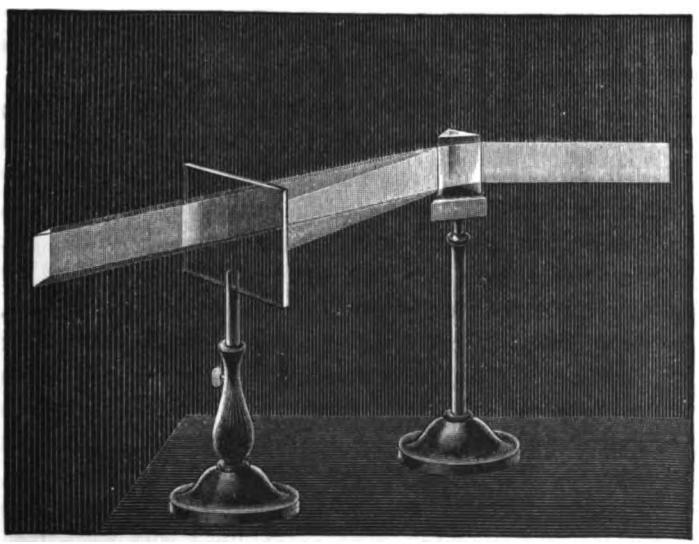
it slowly through the fan of rays produced by the prism. We shall find that the glass throws only an almost imperceptible shadow upon the screen, as long as it is within the sphere of the red and the orange rays; but a totally black shadow at once appears as soon as the strip of glass intercepts the green, blue, or violet rays. Towards the red and the orange rays the red glass acts precisely like ordinary window-glass; towards all other rays it acts like an opaque body, or black glass.

Red glass allows red and orange to pass through, while it destroys the prismatic rays of all other colors. The result must be the same, therefore, whether we place the piece of red glass before the slit, or whether we introduce a larger plate of such glass into the fan of prismatic rays between the prism and the screen. Experiment proves that the same spectrum is produced in both cases. The process by which this result is accomplished is explained by Fig. 7.

Fig. 7.



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Still another method, however, offers itself for proving the correctness of the view just developed. If the effect of the glass rests simply upon the fact that the glass is transparent only for certain rays, while it is opaque for certain others, it must be quite indifferent at what part of the road, which the ray must travel between the source of light and the eye, we introduce the glass. We may therefore hold the latter close to the eye, and may then look at the spectrum upon the screen. In this case we shall also see only the red end of the spectrum, since all colored light coming from the other parts has been intercepted and destroyed by the glass.

Similar results are arrived at, if instead of red glass we employ glass of any other color, or if we make use of a clear colored solution in a bottle, or in a glass tank. In each instance we shall see spectra in which certain colors of the solar spectrum are wanting, and in which that color dominates which is recognized by the unaided eye as the characteristic color of the body under consideration. Using a blue cobalt glass, for instance, we shall see a spectrum in which the whole of the middle region is wanting, and which, besides a narrow strip of red, shows only blue.

20. Opaque colored bodies. The methods just described are not available for the investigation of the pigments used in painting, since most of these substances do not give clear solutions, and since it is of especial interest to observe them when they are laid on in the usual manner. We must therefore proceed differently, and we can reach our end by painting the screen with the pigments to be investigated. Projecting the solar spectrum upon a screen so painted, we shall again see incomplete spectra, such as we saw when employing pieces of colored glass. The best effect will be produced if we leave part of the screen white, and distribute the pigments over the other part in narrow horizontal strips.

Supposing the upper part of the screen to be white, the white being followed by a strip painted red with vermilion,

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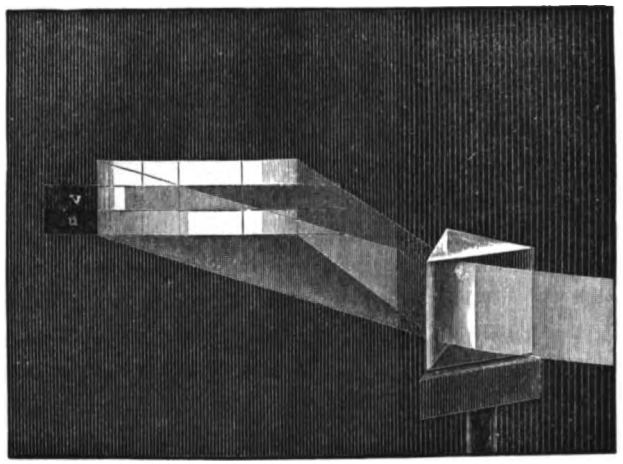
and this again by a strip of ultramarine-blue, we shall see the phenomenon represented in Fig. 8, which latter, although

Fig. 8.



colorless, will be readily understood by the reader, as the colors can easily be supplied by the imagination, their arrangement in the solar spectrum, which is given in the upper part of the figure, being perfectly well known from what has been said before.

In this case, therefore, as in previous cases, the effect of the pigment is shown in wiping out certain of the monochromatic rays falling upon it, while the remainder is reflected.

This wiping out of individual groups of rays takes place quite as well when the combined rays strike upon the painted surface in the form of white light, as when they have been separated from each other by means of a prism.

We can easily convince ourselves of this fact by a simple experiment, which, indeed, offers the readiest means for the investigation of the optical properties of pigments. For it is sufficient to cut a narrow strip (as narrow as it can possibly be made) from a sheet of paper painted with the color in

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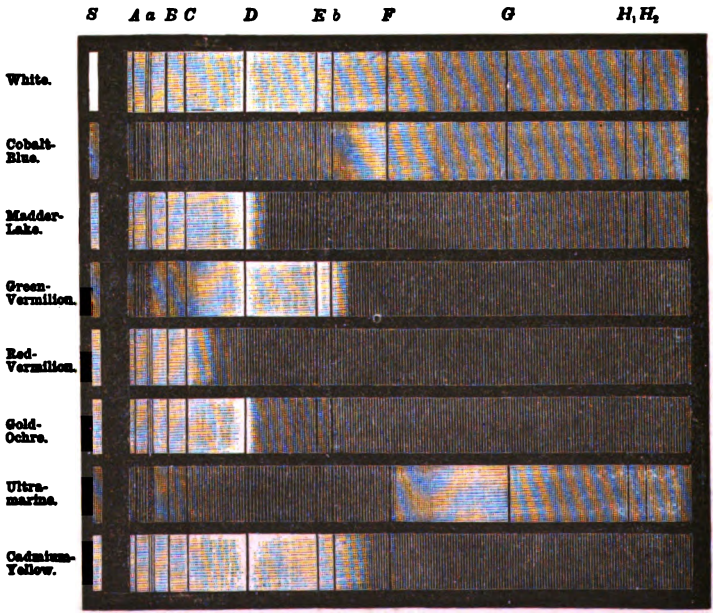
question, to lay this strip upon a piece of black velvet, and to observe it through a prism. We shall then see the same spectrum which we should have seen had we projected the solar spectrum upon a screen of the color of the strip of paper. (Compare pp. 15 and 16.)

The experiment is made all the more striking by painting the strip with different pigments in succession, so that those which are contiguous to each other shall be separated as widely as possible on the color scale. Commencing with white, and following this up by cobalt-blue, madder-lake, green-vermilion, vermilion, gold-ochre, ultramarine, cadmium-yellow, the observation through a prism will show us a series of spectra, as represented in Fig. 9, in which latter the painted strip is indicated by S by the side of the spectra.

Fig. 9.



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21. Absorption. The result of all these experiments may be summed up as follows: —

Pigments, and in general all colored bodies, select certain individual species of rays of definite refrangibility from the light falling upon them, which rays they absorb or destroy. The rays not so absorbed are transmitted, if the colored bodies are transparent, or reflected, if they are opaque.

The process induced by the pigment, therefore, corresponds to the arithmetical operation of subtraction. Certain simple (monochromatic) rays are taken out of the impinging light, and are reflected, while the remainder is destroyed.

An object appears black, if, in the light falling upon it, those species of rays are wanting which alone it is capable of reflecting. If the source of light supplies only part of these rays, the object will show a color different from that which we are accustomed to see in it in white light, and which we therefore call its characteristic color.

These two propositions, which explain a large number of well-known facts, can be proved by various simple experiments.

First of all we can now easily understand why no other pigment is equal to white in brightness. The investigation of the white strip of paper has taught us that such paper reflects all species of rays, if not undimmed, at least equally dimmed, while all colored pigments destroy one or the other part of the light falling upon them, at the same time diminishing the strength of the remainder at least quite as much as white bodies. We can also understand, in the light of these experiments, why a white body always appears of the same color as the light by which it is illuminated.

22. Illumination by colored light. If we illuminate a white surface by red light, either by means of a red flame or by allowing the light to pass through red glass, the surface will appear red.

If, on the contrary, we illuminate objects of different colors

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by monochromatic light, all of them will appear of the same hue, but of different degrees of brightness, the latter being dependent upon the quantity of such light absorbed by the objects, provided that the colored light is really composed of rays of only one kind. The simplest means of producing light which is really monochromatic is found in a flame of alcohol colored by table-salt, or, still better, in a non-luminous gas-flame (such as used for cooking purposes in a gas-stove), into which a few grains of salt have been introduced on a platinum wire. Such a flame emits pure yellow light of the refrangibility of the line *D*. Its spectrum consists of a single yellow line, which corresponds exactly to the dark line *D* of the solar spectrum, and which, like the latter, is resolvable, by very powerful apparatus, into three lines placed closely together.[2]

If such a flame is lighted in a perfectly dark room the only color that can be observed is yellow in its various shades towards black. The whole apartment, with all its contents, has the appearance of a monochrome executed in gray tints, and looked at through yellow glass. Vermilion reflects only a small quantity of light of this degree of refrangibility. A surface painted with vermilion therefore appears of a pure gray in such light. The human face assumes a sallow look, while red cheeks appear to be fallen in and hollow. A sample-chart of colors shows nothing but gray tints. But as soon as we light an ordinary candle, a piece of wood, etc., in this yellow flame, the various colors suddenly emerge from out of the darkness, and the observer feels as if he had been freed from oppression and discomfort.

From these experiments on the absorptive effect of pigments, it will easily be understood why an object exhibits its color more vividly when illuminated by light of the same color. In such a case it absorbs as little as possible of the light falling upon it, but allows nearly all of it to be transmitted or reflected. All colored bodies act like white bodies

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towards light of their own color. If we illuminate red figures upon a white ground with red light, the figures will disappear.

The simplest method of producing light of one color, identical with the characteristic color of a given body, consists in reflecting back light from the same body. If the light so reflected from one part of the body falls back upon another part, it will only be weakened very immaterially by a second reflection. For, while a large quantity of white light, as we shall see further on, is thrown back together with the colored light in the case of a single reflection, this white light will be especially subject to absorption by a second reflection. In the case of repeated reflections from surfaces of a like nature, the portion of white light will therefore diminish continually, while the characteristic color increases in decision, or, in the language of painters, gains in fire and in depth.

This fact has long been known to artists. They are quite well aware that folds of drapery not only show darker shades of the color of the drapery itself, but that the color in these folds is much fuller and deeper than in other parts. The case is similar when a piece of drapery is illuminated by the reflection of a body of its own color. A red cloak in a room with red walls is more brilliant on the side turned towards the wall than on that which is turned towards the window. A gilded niche shows yellow tints of a much greater depth than a plane surface covered with the same gold. Ornaments of gold on concave surfaces are much more effective than upon convex surfaces. Gold frames with ornaments and mouldings in high relief, and with deep hollows and flutings, appear to be different in tint from flat frames gilt in precisely the same manner.

The inside of a golden goblet shows to the observer a color which is entirely different from that of the outside. For this reason no person will ever think of gilding the outside of silver vessels, while it is customary to cover the inside

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with gold. In the latter case each metal can fully develop its peculiar beauty, the silver exhibiting its lustre, the gold its color.

23. Colors by lamplight. If an object is illuminated by colored light which is composed of several simple colors, it cannot show the color which is peculiar to it in daylight, unless the source of light emits all the rays which the object is capable of reflecting. In the light of lamps and of candles the blue and the violet rays are present much more sparingly than in daylight. This explains why red and yellow dresses show pretty much the same color in both lights, while blue stuffs can hardly be told from green by lamplight, and violet dresses appear red, or of a disagreeable gray, according to the dyestuff that has been used. Green pigments principally reflect green and blue rays in daylight, while blue pigments reflect both these species of rays, although in other proportions, and, very generally, also some violet rays. Therefore, whenever the impinging light contains but little of blue and of violet, the green as well as the blue pigment will principally transmit green rays to our eye, and both of them must consequently appear to be green. It is quite possible, however, that our judgment, having been misled by these circumstances, may induce us to take both pigments for blue. Violet pigments, which reflect either blue and red or blue and violet, are similarly affected. Those of the former category will tend towards red by candlelight, or rather, owing to the low power of this kind of light, towards reddish brown, while those of the latter will appear gray.

These conditions can be very well surveyed by the aid of Fig. 10, which represents the spectra of Prussian-blue and of Prussian-green by daylight as well as by lamplight, the spectra of the two sources of light having been added for the purpose of comparison.

Ladies are well acquainted with the changes which colored dress-goods are liable to undergo in different lights; they con-

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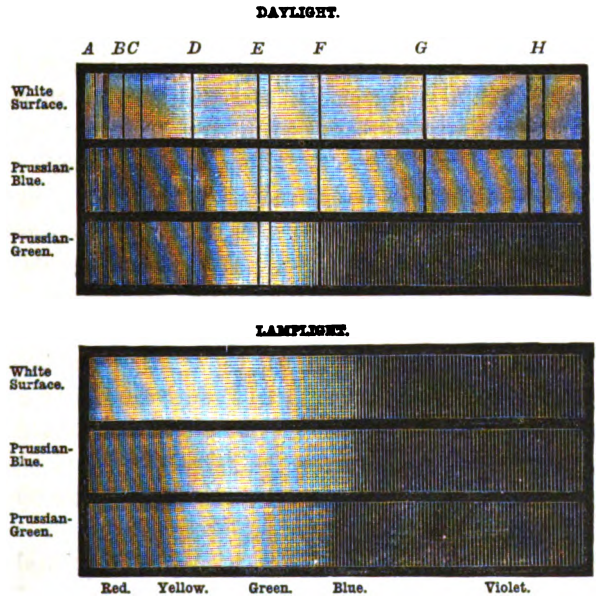
sequently take good care not to purchase by daylight anything intended for their evening toilet, or *vice versa.*

In the decoration of apartments which are especially intended to be used at night, these conditions ought likewise to be taken into account, and all colors which have their place towards the violet end of the spectrum ought only to be

Fig. 10.



employed with the greatest care. It will always be best to execute the sketches for such decorations by lamplight, or at least to pass judgment upon them in such light, before adopting them.

An approximate idea of the impression which paintings, etc., will make by lamplight, can also be gained by looking at them through a piece of glass of a light orange-yellow tint. Glass of this color weakens the rays which are more abundantly present in daylight than in lamplight, and there-

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fore offers to the eye of the observer the same conditions which are produced by the light last named.

To find some method of illumination which will equal daylight as much as possible, is a problem the solution of which is more difficult, and at the same time of much greater importance. In the electric light, in burning magnesium, in Drummond's calcium-light, we have indeed been made familiar with sources of light which fulfil most excellently all the necessary conditions, but the employment of these aids must always be quite restricted, on account of their costliness.

In some cases, however, the end just alluded to may be reached by a simpler proceeding, according to a proposition lately made. If we allow lamplight to pass through a weak solution of sulphate of copper, this solution will principally weaken the red and the yellow rays, that is to say, those rays which are in excess in lamplight. With the proper degree of concentration in the solution the light transmitted will therefore be equal to daylight in its composition. To compensate for the resulting loss in brightness, the solution may be poured into a spherical flask (a so-called Florence flask with a globular body), or still better into a glass globe, and this flask or globe may be so fixed between the flame and the object to be illuminated, that the latter is within the cone of concentrated light, which is formed behind the globe.

In dye-houses, and in assorting or comparing colored goods, this contrivance may be of some use in night-work. To fit it for more general application, however, the idea needs to be still further elaborated.

If it is not necessary to exhibit the result simultaneously to a number of persons, the transparent colored medium can always be held closely up to the eye, instead of introducing it between the source of light and the object. Whenever we look at an object through a piece of colored glass, we receive precisely the same impression which we should receive, if we were to allow the light to pass through the glass before it

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falls upon the object to be illuminated. Red figures upon white ground, for instance, will disappear when looked at through a piece of red glass, just as in a former experiment (see p. 42), in which the same figures were illuminated by red light, while green figures will appear black. The changes in the proportion of brightness, which may be studied by experiments of this kind, are also very interesting. If, for example, we place a dark red (carmine) piece of paper upon a bright green (emerald-green, Paris-green) ground, and then look upon the whole through a piece of red glass, the red paper, which at first appeared to be much the darker of the two, will show brightly upon a dark gray ground.

The colored plates of this book furnish excellent objects for experiments of this kind, which can easily be repeated by the aid of a few strips of colored glass or gelatine, such as can everywhere be bought for a few cents.

24. Influence of the thickness of colored media.

But the experiments on the effects of pigments thus far described do not nearly exhaust the subject. The impression made upon us by a body colored naturally or artificially depends upon a number of accessory circumstances, which it is indispensably necessary to understand, if we desire to gain a more than superficial insight into these phenomena. Oil-colors and water-colors, transparent colors and body-colors, possess optical properties which are peculiar to each; and woven fabrics more especially, although of precisely the same color in the thread, may look entirely different from each other, if the one be plain while the other is figured, etc. Even the phenomena to be observed, when making experiments with colored glass or clear colored solutions, need a closer study than we have heretofore devoted to them.

If we employ layers of various thickness, which may easily be produced by placing several pieces of colored glass upon each other, we shall find that a change of color takes place. If the latter was originally weak, it will grow stronger and

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stronger with the growing number of pieces of glass, but at the same time the light transmitted will continue to decrease in strength, until finally no light whatever is transmitted, and the layer of glass appears to be black. If the layer be thick enough, even so-called white, or, more correctly speaking, colorless glass will exhibit a definite tinge, mostly of a blue or green hue. The effect produced, in the case of glass, by the thickness of the layer, is produced by concentration, in the case of colored solutions. A drop of ink in water will impart to the latter a bluish or violet tinge, or it may be a greenish or reddish tinge, according to its composition, while in a concentrated state the ink looks quite black.

This change in the brightness of the transmitted light is, however, accompanied by a change of hue.

A solution of sulphate of copper, made from those beautiful blue crystals which are so frequently seen in the show-windows of druggists, has a pale greenish-blue hue in a diluted state, while in a state of concentration it is of a deep blue. A few drops of claret poured into water produce a disagreeably grayish tinge, and it requires a much larger quantity before we can recognize the red color of the wine. Similar observations can be made with transparent colors. Madder-lake, laid very thinly on white ground, produces a yellowish, Berlin-blue a greenish-blue tinge, etc.[3]

The red flashed glass before mentioned, that is to say, ordinary glass covered with a thin layer of glass colored by the protoxide of copper, shows a more yellowish hue when the covering is very thin, or has been reduced by etching, than when it is of its usual thickness. Etching has therefore been employed to produce patterns upon such glass of a peculiar chromatic effect.

The explanation of all these phenomena is to be found in the fact that the colored media at first exercise their absorptive power upon certain definite species of rays, and then gradually extend it to the others. Solutions of indigo, for

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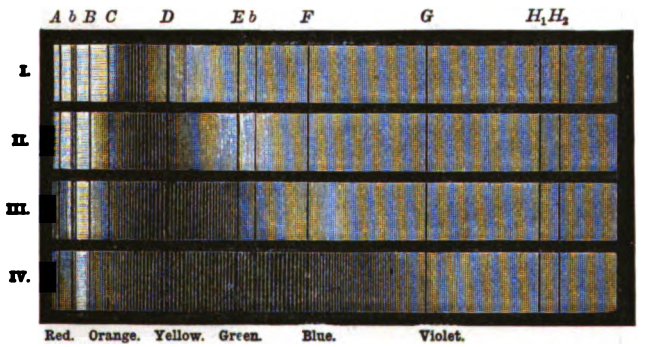
instance, of different degrees of concentration, show well-marked differences of color. A very weak solution appears light blue with a tendency towards green, so that it might easily be mistaken for a solution of Prussian-blue; but as the solution gains in concentration, it assumes hues of a strong blue, and finally passes into colors showing an unmistakable tinge of violet.

Investigating such solutions by means of the prism, we obtain a series of spectra, such as are represented in Fig. 11.

Fig. 11.



As the same result is reached by employing an increasing volume of the weakest solution, the process which takes place when the prismatic fan of colors enters such a solution may be represented to the eye by Fig. 12.

25. Influence of repeated reflections upon the hue. Repeated reflections from the same surface are accompanied by similar processes, and this explains why, in the case of such reflections, the color does not only invariably increase in depth, but also frequently shows slight changes in hue. The *folds* of drapery not only appear fuller in color, but they likewise gain in warmth, as the artists express it.

The physical processes which take place under these circumstances are of a tolerably complicated nature. To understand them is of great importance to the painter as well as

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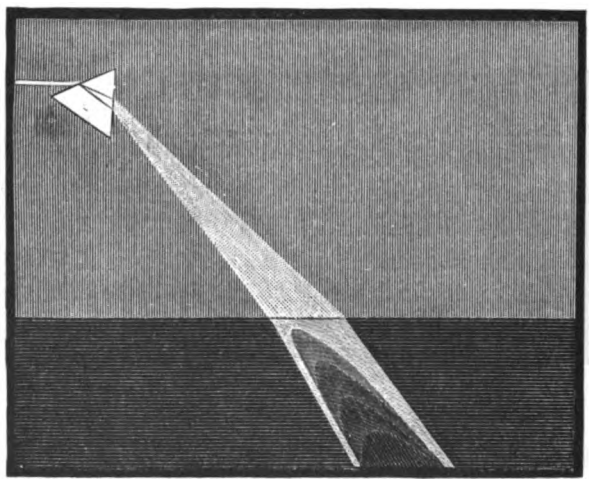
to the decorative artist. The following experiments and observations are therefore devoted to the consideration of these processes.

26. Regular and irregular reflection.

If, in a perfectly darkened room, which is only sparingly lighted by a very small source of light (a small flame), we lay a piece of white paper on a table, alongside of a very good looking-glass,

Fig. 12.



best of all a black glass (Claude glass), or of a tray filled to the brim with perfectly pure mercury, we shall find that the surfaces of the paper and of the glass differ totally from each other in their action. The paper surface can be seen from any part of the room from which we can look upon the table, while the looking-glass is only visible in certain situations admitting of definite relations both to the glass and to the source of light, that is to say, in a position in which it is possible to see the reflection of the flame. Hence it follows, that both bodies reflect the light falling upon them, but while the paper sends it forth in *all* directions, the looking-glass

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reflects it only in *some* directions which can be accurately defined. In consequence of the difference in the reflection from these two bodies, the reflection from the looking-glass is called regular, while that from the paper is called irregular. All smooth bodies reflect regularly, all rough bodies reflect irregularly. In most cases, however, we meet with both kinds of reflection together, although one of the two is generally found to predominate. Every particle of dust upon the surface of the looking-glass sends back in all directions the light falling upon it, and the same is true of any other impurity upon the reflecting surface. On the other hand, it is quite as difficult to produce perfectly dull surfaces; nearly all of them possess a trace of gloss, that is to say, they reflect a part of the impinging light regularly. Among white bodies moulded plaster of Paris is the freest from gloss.

If bodies, the surfaces of which are of a nature to reflect light regularly, are reduced to powder, each particle will indeed continue to reflect regularly for itself; but, since the position of the surface of each of these particles varies, the direction of the light reflected by each particle must also vary, and hence it follows that any such powdered body must throw back the impinging light in all directions. Each crystal of ice as it falls from the clouds in the shape of a snow-flake is colorless and transparent, and has a surface which reflects with perfect regularity; a snow-covered plain, however, appears white and without gloss. Powdered glass, or the powder of any other transparent, colorless crystals, shows the same phenomenon. Water in the form of spray, or effervescent soda-water, appears white and without gloss, for the same reason.

It is self-evident that a change in the surface of a body is sufficient to convert regular into irregular reflection; as soon as the regularity of the surface is disturbed, the body loses its gloss. It is frequently almost impossible, in calm

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weather, to perceive a pond, surrounded by the trees of a forest, as the eye is deceived by the reflected image of the trees; but the faintest breath of wind suffices to destroy the phantom, and the presence of the water is immediately betrayed by the slight agitation of its surface.

27. Color of reflected images. Turning our attention to the *color* of reflected images, we shall find, as a rule, that the latter appear in the color of their originals, at least in those cases in which we have to deal with a reflection which does not proceed from the lower surface of a transparent body, as in the case of a common looking-glass, but which is produced by the surface nearest to the eye. If, for example, we smoke pieces of glass of different colors on one side, so that on this side they will neither allow light to be transmitted nor reflected, and if we then use the other side as a looking-glass, we shall observe that the effect of the color of the glass upon the color of the image is very slight. All the reflected images will show their natural colors tolerably well, although considerably enfeebled, as in a black glass (Claude glass).

28. The vehicles used in painting. Phenomena similar to those produced by the reflection of light are also met with when light is refracted. At the boundary planes of a transparent body light is refracted regularly, provided that these planes are regularly formed. We can see without obstruction through a plate of glass with finely polished, even, parallel surfaces, although the light is refracted twice before it enters the eye. As soon, however, as one of the surfaces loses its regular geometric form, the rays of light which fall upon it parallel to each other can no longer enter the plate of glass in the same relative position, but they are, on the contrary, refracted in all conceivable directions. Under these circumstances the body is no longer transparent; it is only translucent. Glass which has been ground loses not only its power of reflecting, but also its transparency.

In the application of colored bodies, however, we have not

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only to deal with *two* boundary planes, or, in other words, with the front and back surface of a layer of coloring matter, but there are frequently a very large number of such planes of separation. Pigments are applied by the aid of a fluid vehicle which transforms them into a paste, and allows them to be laid on with a brush, while at the same time it makes them adhere to the surface which is to be painted. This vehicle, or medium, after the pigments have been applied, undergoes certain lesser or greater changes, according to the technical process employed. The smaller the optical changes which the medium undergoes in drying, the more perfect will be the process, for the artist will be better able to judge of the final effect of his work while it is still in progress, and he can therefore attain a perfection which it is impossible to reach when the work is subject to important changes after its completion.

It has been admirably well shown by VON PETTENKOFER, that the great superiority of oil painting over every other kind of painting rests upon this fact. In oil painting oils or gums are employed as media, which, while they harden on being exposed to the air, do not change materially in their optical action. The artist can therefore judge of the relative effect of his colors much more readily during the progress of his work when painting in oil, than when he paints in water-colors, or "al fresco," or upon porcelain, for in these latter cases he must always take into account the changes produced by drying or baking. All prominent colorists, with perhaps the single exception of CARL ROTTMANN,[4] have therefore shown a decided preference for oil-colors in the execution of their works, as in all other manners of painting it is hardly possible to avoid a certain conventional treatment. It is also owing to this fact that the highest demands are made upon an oil-painting in regard to color. While of the fresco-painter, in view of the surroundings among which he generally unfolds his activity, and of the space which he requires

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for his creations, we ask above all great power in composition and in drawing; and while in a water-color painting neatness and delicacy of execution often induce us to overlook other defects, we are apt to excuse anything rather than bad color in an oil-painting. Although water-color painting is in reality beset with greater difficulties than oil painting, it will nevertheless be much easier for an amateur to execute a passably good water-color than an oil-painting, in which latter mediocrity is simply intolerable.

The part enacted by the medium, which, as may be seen from what has just been said, is of sufficient importance to warrant a more detailed investigation, can be best illustrated by the following experiments.

If we fill the lower part of a small glass tube (a test tube) with coarsely powdered glass, the powder will appear white, and it will be impossible to see through it; but as soon as we pour water into the tube the powder will become translucent to a certain degree. By substituting turpentine for the water, the degree of translucency is considerably increased. Furthermore, if we add a small quantity of sulphuret of carbon to the turpentine we shall obtain a liquid which refracts the light about as powerfully as glass, and if we now pour some of this liquid upon the powder, the latter will disappear almost entirely to the eye, and we shall be able to look through the glass freely, as if it contained only the clear fluid without the least particle of the powder. If we immerse a glass rod in such a liquid (instead of which we

Fig. 13.

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may also employ a mixture of olive-oil and oil of cassia), it will appear as if the rod reached only to the surface of the liquid. Within the liquid itself the presence of the rod cannot be detected; it is perfectly transparent, as shown by Fig. 13. Instead of the powdered glass, small beads of transparent, colorless glass may also be used. They will become invisible as soon as the liquid dislodges the air between them.

It is shown by these experiments that the presence of one transparent body within another is only betrayed to the eye when the two differ in their power of refracting light. If this is not the case, the light passes through the mixture without obstruction.

29. Transparent colors. These two groups of mixtures (of bodies which are in themselves transparent) correspond to the transparent colors and the body-colors of the artists. Only metals, and bodies of so-called metallic lustre, impart color even to those rays of light which are reflected from their surfaces; in the case of all other bodies, on the contrary, the light which penetrates into them is colored by the process of absorption. It follows that all pigments must be transparent, at least in very thin layers, and that even the effect of a body-color can only be produced in the manner just explained.

Transparent colors are similar in their action to colored glass, or to clear colored solutions. They are best adapted, therefore, to give us an insight into the process which takes place when light falls upon a transparent substance which is colored throughout its whole mass, for as such we may look upon a layer of glazing color. In this case a reflection primarily takes place at the upper surface *S* (see Fig. 14), and this reflection is generally regular, as a transparent color dissolved in oil, varnish, or gum-arabic will always possess a smooth, shining surface, like that of a plate of glass which has not been purposely deprived of its lustre by grinding. This reflection, however, extends only to a fraction of the

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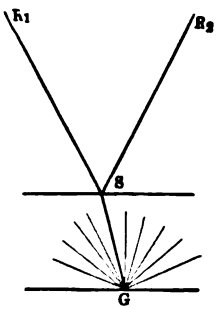
impinging light; the remainder enters the colored mass, and there undergoes the process of absorption, previously explained in detail, so that it is already decidedly colored when it arrives at the ground surface *G* of the layer. If at this second surface the light strikes upon a white body which reflects irregularly, colored rays will be emitted from this layer in all directions which face toward the impinging ray of light, and in the repeated penetration of the colored layer their color will increase in intensity. An eye observing such a glazing upon white ground will receive therefore intensely colored light, which is only mixed with the white light reflected from the front surface. If the reflection at this front surface is regular, the light which is thrown back by it will take its course in certain definite directions. By placing the eye at some point which is not within the region of the bundle of these reflected rays, we shall only see light which is irregularly reflected from the lower surface, or ground, and which has therefore travelled twice through the colored layer. In this manner we receive only light of intense color, with a very small admixture of white light.

Fig. 14.



30. Varnish. In oil painting the removal of this superficially reflected light, by means of regular reflection, is secured by the varnish. The varnish gives to the picture a glossy surface, which, indeed, reflects a large quantity of foreign light in certain directions, that is to say, light that has not been changed by the pigments of the painting, but which is simply and solely dependent upon the source of light, and therefore produces a discordant and troublesome effect. The course of this foreign reflected light, however, for the very reason that it is thrown back only in certain well-definable directions, which are determined by the relative

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position of the painting and of the source of light, can easily be ascertained beforehand, so that from all points outside of the lines of reflection the color will show with much greater intensity and purity.

An oil-painting which has lost its glossy surface by the drying of the oil, which has "sunk in," as it is called, does not show this regular reflection. In such a case the white light produced by superficial reflection is no longer carried off in certain directions, but is scattered in all directions. It therefore exercises its unpleasant effect under all circumstances, and the colors in such an oil-painting look dull and dead, no matter from what point we may be looking at them.

81. Body-colors. Body-colors differ entirely in their action from transparent colors. They are likewise transparent in very thin layers, and with them it is also the light that has passed through the pigment which exhibits the characteristic color of the latter; but the great difference in the optical action of the pigment and of the vehicle or médium, makes it impossible for the light to penetrate through layers of any perceptible thickness. On account of this difference a division into transmitted and reflected light takes place at all the surfaces of separation of the particles of the coloring matter, so that the portion of transmitted light is already reduced to an almost inappreciable quantity at an insignificant depth below the surface. The same is of course true of the light sent forth by the lower surface, and this explains why such colors are opaque when applied in tolerably thick layers. As the light is not essentially altered in its composition, or, in other words, as it is not colored by reflection from the surface of the particles of the coloring matter, it follows that light reflected by body-colors will always contain a larger quantity of white light than light that is reflected by transparent colors. This is the reason why that brilliancy and depth, or, as we shall say hereafter, that *fulness*, can never be attained by body-colors which can be

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obtained by using transparent colors. It will also be easy to understand, from what has just been said, why those parts of a painting which have been glazed are principally brought out by the varnish, since in their case all interfering light is removed with the removal of the light superficially reflected, while in the case of body-colors, even the deeper layers continue to send back white light, which mixes with the colored light.

32. The regenerative process. The correct recognition of the part played by the vehicle in painting led VON PETTENKOFER to the important discovery of the process of regeneration. He perceived that the dimness of old oil-paintings, which had formerly been explained by the supposed formation of mould, is caused by minute fissures in the vehicle. These fissures interfere with the transparency of the vehicle, and the quantity of white light superficially reflected is increased by them beyond all proportion. The fumes of cold alcohol are sufficient to so far soften the gums used in oil painting, or the oils which have become resinous, as to cause these fissures to close again, thus allowing the colors to reappear in their original power and freshness.

33. Optical effects of woven fabrics. Processes analogous to those just discussed also take place when light falls upon dyed woven fabrics, and upon these processes principally depends the impression made upon the eye by such stuffs. The fibres composing the threads of woven fabrics are in themselves transparent, and in dyeing the coloring matter so combines with them that they appear colored throughout, like threads of colored glass. But between these fibres there is air, and the light which falls upon any such woven stuff will consequently suffer a division into transmitted and reflected light at the surface of each fibre. By selecting different ways of weaving, we are enabled to vary this proportion of white light at will within tolerably wide limits, and at the same time to transform the irregular reflection more

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or less into regular reflection; that is to say, according to the manner of weaving chosen, we can produce stuffs with or without gloss, and in the case of those without gloss, velvet for instance, we can reduce to a minimum the white light irregularly reflected.

But we must also take into account the fact that regular reflection from woven fabrics differs materially from the same reflection from a plane glass surface. This difference is caused by the position of the threads, by which certain definite directions are rendered conspicuous as regards their power of reflection. Taffeta, for instance (Fig. 15), or ordinary linen, reflects most strongly in two directions, which are perpendicular to each other.

Fig. 15.

Taffeta.

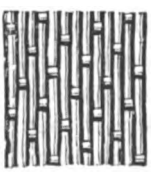
In the case of a twill (Fig. 16), special stress is furthermore laid upon one of these directions, unless it be what is called in French an *etoffe sans envers*, that is to say, a fabric both sides of which are alike.

Fig. 16.

Four-shaft Twill.

This is true in a still higher degree of satin, which must indeed be classed with the twills, but in the weaving of which the warp is carried a great many times across the woof, and in which the threads of the latter are besides allowed to be seen only at very irregular intervals, so as to avoid the diagonal lines which are peculiar to the ordinary twill. In this manner all the stress is laid upon the threads of the warp (Fig. 17), which run parallel to each other, and especial prominence is therefore given to this one direction.

Fig. 17.



Satin.

It follows from this that the observer, according to the position occupied by him in relation to the piece of satin and to the source of light, at one time principally receives reflected light, while at another he receives light coming from

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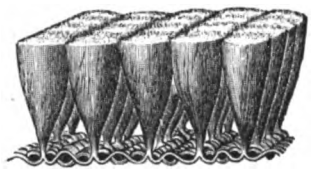
the shadowy furrows lying between the threads of the warp. Hence in the first case the *gloss* will mainly assert itself, in the second the *color*. These conditions can very well be studied by laying long, bright needles, best of all knitting-needles, alongside of each other, and observing them from different positions.

In weaving satin, by allowing the warp and the woof to exchange places within certain prescribed limits, we obtain the damask, in which the pattern simply becomes visible by the difference between superficially reflected light and colored light coming from below the surface.

Fig. 18.



Velvet.

The case is quite different with velvet, the structure of which may be compared to that of a brush (Fig. 18); while the gloss or lustre of satin is its most valued property, the principal endeavor in the production of velvet is directed towards excluding, or at least reducing to a minimum, the light reflected from the surface.

Regular reflection, and consequently all gloss, properly speaking, is therefore avoided almost entirely in velvet, as only the very uppermost points of the threads can throw back colorless light, and then only irregularly. By far the greater part of the impinging light can reach the eye only after it has travelled over manifold and long paths between the individual threads; it follows that the color of this light must be exceedingly full, but that at the same time it must have lost considerably in brightness. Velvet consequently continues to show the color of the threads with only an insignificant admixture of white, even when illuminated and looked at in a very oblique position, while, when seen from above, it possesses a depth (fulness) which is equalled by no other woven fabric. The processes which here take place are indeed the same that may be observed, although

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in a much lower degree, in a piece of cloth folded into very many and very deep folds. We therefore meet in velvet with the same differences in hue between the surface color and the highest lights, which are shown by dresses with deep folds made from other fabrics.

Satin and velvet form the two extremes in woven fabrics; in the former we value its gloss, in the latter its color. And we shall actually find, that, while there are certain definite colors which are especially well adapted to satin, there are also others which are equally well adapted to velvet, — a circumstance which will offer a useful hint to us at a later stage of our discussion, when investigating the theory of the sensations of color.

34. Surface colors. But even after considering all the phenomena described in the previous sections of this chapter, the theory of inherent colors is still far from being exhausted. Only certain groups of bodies owe their color to the process of absorption previously explained in detail, while there are also other bodies which cause a division of the light falling upon them; bodies, that is to say, which allow rays of a specific degree of refrangibility, or, in other words, of certain colors, to enter, while they reflect all others. Such bodies show one color when the light falls upon them, and another when the light is transmitted through them. In their case even the light superficially reflected is colored, and they are consequently called bodies with "surface-colors."

The metals are especially prominent in this class of bodies. Very thin leaves of gold show a beautiful bluish-green color when the light is transmitted through them; very thin layers of silver, such as are obtained in the manufacture of silver looking-glasses, show a deep blue under the same circumstances; while it is a well-known fact that the reflection of a white body appears yellow on a golden surface, or even orange after repeated reflections, and yellowish white on a silver face. The various aniline pigments also show such

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surface colors when dry. If we produce thin layers of these pigments, by allowing small quantities of their solutions to dry upon glass plates, these layers will have a perfectly metallic appearance. Fuchsine or magenta, for instance, has a greenish-golden color when the light falls upon it, a purple color when the light is transmitted through it.[5] Of the pigments used in painting but very few show such surface-colors, and these few only in an insignificant degree. Indigo, for instance, when seen in pieces, shows a slight tinge of coppery red, and the same may be said of Berlin-blue, although in its case the tinge is still fainter.

The surface-colors fortunately step into the background when the pigments named are used in painting, or when the aniline colors are used in dyeing. We can therefore spare ourselves the trouble of investigating the very interesting but complicated phenomena which are connected with them, and which are still but incompletely understood.

35. Phenomena of fluorescence and iridescence.

But apart from the bodies with a metallic lustre, for thus we may also designate the bodies showing surface-colors, we shall find still others which again act quite differently, in regard to color, from the bodies previously investigated.

In all the cases so far discussed the phenomena of color were explained by showing that a division of the impinging rays took place, that a part of these rays entered the body or passed through it, and that the remainder was absorbed or reflected. But there are also bodies which transform the light falling upon them into light of another color, that is to say, of different wave-length. Such bodies are called *fluorescent bodies*. This transformation of light of a specific color into light of another color gives rise to most peculiar effects of light. These effects are probably most frequently observed in a species of glass to which a yellowish-green color has been imparted by uranium, and which, on account of its peculiar play of colors, is often used for door-knobs, bell-

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pulls, etc. While this glass shows only a faint yellowish-green color when the light is transmitted through it, we can observe strong bluish-green tints in it, of a peculiar nebulous form, when the light falls upon it in a certain manner. These forms can best be seen when we cause the concentrated rays of the sun to fall upon such glass by the aid of a lens, a so-called burning-glass, in which case we shall see a beautiful blue-green cone of light in the interior. Similar phenomena are shown by fluor-spar, whence the word "fluorescence," by the solution of sulphate of quinine, by the extract of the bark of the horse-chestnut, by petroleum, and by a number of other substances, each of which imparts a different color to the cone of light.

Investigations with the aid of the spectrum show that in the case of bodies of this kind light of the most varied colors is transformed into light of some other definite color, and that even invisible rays can be changed into visible. In some of these bodies we possess a ready means for making the ultra-violet rays, which are invisible under ordinary circumstances, perceptible to the eye, that is to say, of transforming them into visible rays. Even the ability of our eye to see the ultra-violet rays of the spectrum under certain circumstances without the intervention of any artificial aid (see p. 22), rests partly upon the fact that the retina possesses in a slight degree the property of fluorescence, and can therefore render visible a small fraction of those rays to which its nervous apparatus is in itself insensible.

A detailed investigation of this group of phenomena of color may also be dispensed with here, as they are of no importance to the arts.

The same is true of long series of other phenomena, which are of great interest to the physicist. I will only call to mind the colors of the soap-bubble, of mother-of-pearl, and of other iridescent bodies; those of the coronæ seen around the sun and the moon, as well as to the magnificent phenom-

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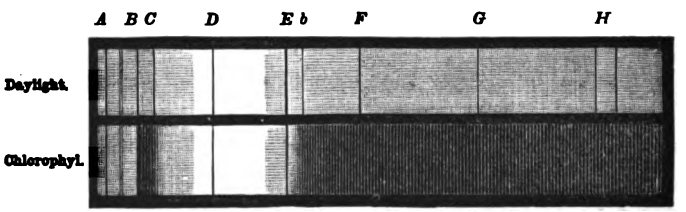
ena which are offered by crystallized bodies in what is known as polarized light. Readers who take an interest in this matter must be referred to other works, such as DOVE'S "Theory of Color," or PRISKO'S "Light and Color."[6]

36. Chlorophyl. We must, however, investigate the colors of a few bodies which the artist meets invariably in all landscapes, and the peculiar action of which makes them worthy of separate study. The colors alluded to are those of leaves, the coloring matter of which is known as chlorophyl, of the sky, and of water.

The color of chlorophyl in its dry, undissolved state, as it is present in the leaf, is a color produced by absorption, like those of the pigments which are used in painting. But it is nevertheless distinguished from the latter by a very peculiar spectrum, an analogue for which would be sought in vain among the pigments of artists. The spectrum of chlorophyl, as we can obtain it by projecting a spectrum upon the green leaf of a plant, does not show shadowy bands, which are tolerably broad and are gradually lost in a half-shadow, such as the spectra of pigments represented on p. 40, but it shows, on the contrary, a single very strong and pretty sharply defined black band in the red (Fig. 19), together with an ab-

Fig. 19.



sorption which, commencing with the bluish green, extends with increasing strength over the whole of the refrangible part of the spectrum.

Leaves, therefore, reflect not only the yellow, green, and bluish-green light, but also the red, which is the least refran-

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gible. Green leaves consequently look red when illuminated by red light, while a green dress, or green paint, generally looks gray or black under the same circumstances. If the impinging light, besides the red, contains also yellow rays, the leaves will show a yellowish-red color, while in a light in which these two kinds of rays are only sparingly represented they will have a glaringly green or bluish-green appearance.

These statements will serve to explain the great differences existing between the illuminated trees in a landscape and those in shadow. The direct light of the sun, especially when the latter is near the horizon, is mostly made up of red, orange, and yellow, while these colors are only sparingly represented in the reflected light of the heavens, the so-called light of the sky.

This is the reason why at sunset, and especially in mountainous regions with rich vegetation and a luxuriant growth of grass, very harsh combinations of color are frequently produced, which are heightened still further by effects of contrast, and which, from an artistic point of view, it is often impossible to call beautiful.

We can convince ourselves by a very simple experiment of this action of chlorophyl, which differs so widely from the action of other green substances. If we employ the same artifice which we have already employed before, that is to say, if, instead of throwing red light upon leaves, we look at plants, illumined by daylight, through glass which transmits only such red light, we shall find that the landscape offers a very curious aspect. All green plants are relieved in bloody red from a dark black sky. A green dress, on the contrary, green blinds, etc., appear dark and perfectly colorless.

Unfortunately, we are not in the possession of any red glass which will allow only red light to pass through it, for all kinds of this glass transmit also some of the orange and the yellow rays, although not as freely as the red. To reach our purpose we must therefore make use of a combination of

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different kinds of glass. We can obtain such a combination which has been called an *erythroscope*, by laying a piece of deep yellow glass and another of violet glass, one over the other; or, for want of a better, we may even substitute for the violet a piece of cobalt-blue glass, as the latter likewise transmits certain red rays. Indeed, such a cobalt glass is in itself sufficient to give a delicate reddish hue to the vegetation if the light is favorable.

This experiment can be made much more striking by proceeding as follows: Take a number of pieces of green cloth or paper which to the eye appear to be of about the same color as a natural leaf. From these cloths or papers select one which, when looked at through the erythroscope, appears to be perfectly gray or black. If the natural leaf is now laid upon this ground, and the erythroscope is held up to the eye, the leaf will suddenly appear in a vivid red upon a dark ground, while before it could hardly be told from its surroundings. A very strong light is however needed for this observation, best of all the direct light of the sun, as the erythroscope allows but little light to pass through. A special selection of the cloth or paper to be used as a ground is necessary, because, after all, some of the green pigments also reflect red light, although their spectra are not identical with that of chlorophyl.

The experiment just described forms the counterpart of that mentioned on p. 47. There the red figures on white ground disappeared when looked at through red glass; here a green leaf is suddenly relieved from a ground of the same color.

Among the green leaves of artificial flowers it is also quite easy to find some which appear gray when looked at through the erythroscope. Having mixed such leaves with natural leaves, it is very surprising to see how we can tell the one from the other, even at a distance, with the aid of the erythroscope.

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The solution of chlorophyl, such as may be obtained by treating leaves with alcohol, acts very differently from solid chlorophyl. This solution belongs to the fluorescent bodies, and exhibits phenomena which are quite as beautiful as they are curious.

37. The color of water. Water is another of those bodies, of which the magnificent play of colors offers the greatest interest to the landscape artist. It is a well-known fact that large masses of pure water show a blue or green color, but many persons are still quite insufficiently informed concerning the origin of this color. The circumstance that the reflection of the sky on the water exerts a material influence on the phenomena shown by the latter, has given rise to a very widespread but erroneous supposition. It has been assumed that the cause of the color of the water must be sought in these reflections only, and this supposition has prevented the acceptance of the simple idea, that water possesses a color of its own, like any other colored liquid, although the fact that the purest water, that of the glaciers, shows the peculiar color of water more beautifully than any other, and does not appear gray, even when the sky is overcast, speaks very loudly for the simple explanation just given.

We will now explain how it may be shown that water really possesses a color produced by absorption; and after having settled this point we will proceed to discuss the secondary circumstances, which are instrumental in altering the appearance of large bodies of water, when looked upon as a whole.

The celebrated chemist BUNSEN was the first to prove decisively that water is not colorless. He showed that a white surface appears of a pale blue color when looked at through a tube two metres in length, closed with plates of clear glass at both ends, and filled with distilled water. In this respect, therefore, water is similar to window-glass, for

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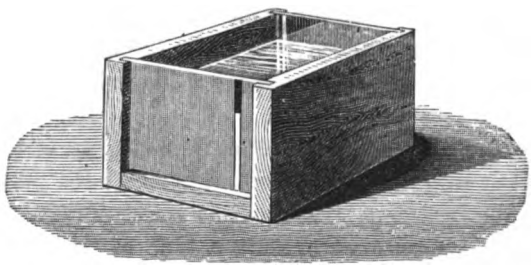
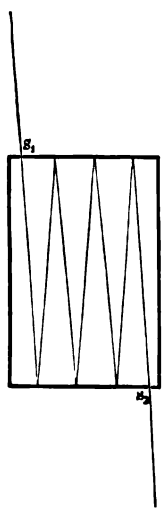
Fig. 20.



this likewise shows a bluish-green color, provided that the layer through which we are looking is of sufficient thickness.

Fig. 21.



This experiment has been reduced to a very simple form by Professor BEETZ. A small, rectangular box is closed on opposite sides by glass plates coated with silver, into which have been scratched fine vertical lines, as shown in Fig. 20. Looking into the box through one of these slits we shall perceive the light entering upon the other side, after it has been repeatedly reflected by the two looking-glasses, and has therefore travelled a very long distance within the box (Fig. 21). If, now, we fill the box partly with water, we must necessarily see that part of the image which is seen through the water, in the color which is peculiar to this liquid. Employing distilled water we shall find the color to be a pure blue, like that of the Alpine lakes. If the water is not perfectly pure, but holds more or less of organic matter in solution, the color will change to green, and finally, in the case of swamp-water, into brown.

The reflection from the surface of a body of water is, however, of material importance as an element of the total

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impression which it produces upon us. When the surface is quiet this reflection may assert itself to such a degree, that the water acts simply as a glass, and that hardly any light from below the surface is transmitted to the eye of the observer.

At the same time the ratio between the reflected light and the light coming from below is dependent upon a number of secondary circumstances. In shallow water with a light colored bottom, the latter can easily be seen beside the reflected image, and the color of the bottom will be but little modified by the thin layer of water. In water of a greater depth, on the contrary, the light transmitted to the eye will be very faint, but decidedly colored, and it will now be easy for the reflected light to gain the ascendency. The spot where this takes place asserts itself in a peculiar manner on the shores of lakes, and needs to be made a subject of special study for pictorial representation.

38. Influence of polarization on the appearance of water. But there are still other peculiar circumstances which come into play when light is reflected by water, and which cannot be left unnoticed. Light which has been once reflected from a *non-metallic* surface acquires certain properties by this process of reflection. One of the most prominent of these is, that its action, upon being reflected a second time, differs from that of light which emanates from a self-luminous or from a rough body.

Physicists call such light *polarized*, and speak of its more or less complete polarization according to the higher or lower degree in which it possesses the properties alluded to. Such polarized light may be obtained in a very simple manner. Lay a piece of colorless glass (ordinary window-glass will do, if plate-glass is not at hand) upon a low table near the window, so that the light from the window falls upon the glass in an angle of thirty-five degrees with its surface. If we now hold a black glass (Claude glass) in our hand in a position which will allow us to see in it the reflected image

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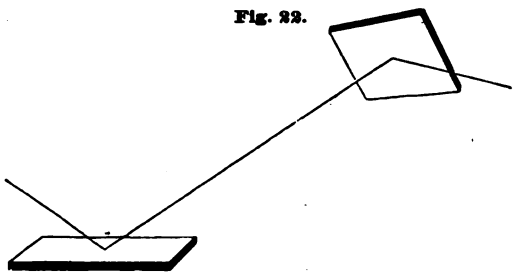
of the piece of glass, and consequently the second reflected image of the window, we shall soon find that the brightness of the latter changes with the position of the black glass. If we select the position indicated in Fig. 22, the image of

Fig. 22.



the window will disappear almost completely, and we shall see the top of the table, or, still better, a figured table-cover, through the plate of glass without obstruction, while the eye, if placed in the position of the black glass, will perhaps be almost unable to discern the table top or the cover, on account of the intensity of the reflection. We can therefore cause the reflected light, produced by a single reflection, to disappear by a second reflection. The same phenomenon can also be observed very markedly by looking at glossy stuffs, such as damask or satin, in a black glass. It will be easy to find positions in which the images of these stuffs, as seen in the glass, show no lustre at all, so that in the case of damask, for instance, the pattern will disappear almost entirely. This effect is best obtained by placing pieces of the stuffs just named in the position previously occupied by the glass, and again holding the black glass in the hand as before. The peculiar action of the light reflected from the plate of glass may also be shown by holding a very thin plate of gypsum (selenite) or of mica, as thin as it can possibly be obtained by splitting with a knife, between the piece of colorless glass and the black glass. Its image in the latter will then appear magnificently colored. It may be well to men-

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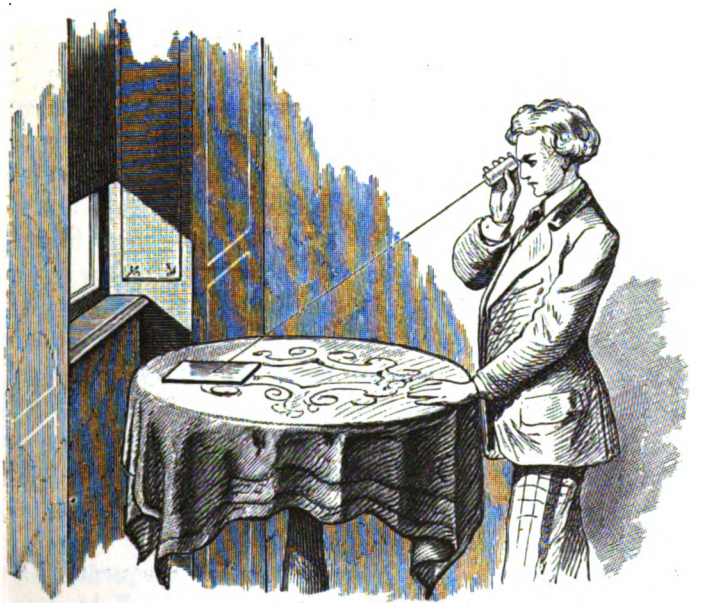
tion here, that a piece of ordinary plate-glass, coated upon its lower surface with india-ink or lampblack, will furnish a black glass which is quite sufficient for making the experiments described.

But physicists possess still other means, besides a second reflection, by which they can cause polarized light to disappear. If we look at the plate of glass through a so-called Nicol's prism, that is to say, an instrument formed by a peculiar combination of two pieces of Iceland spar, and if we now turn this instrument around its longitudinal axis (Fig. 23), we shall notice that there are two positions in

Fig. 23.



which the plate of glass with the reflected image of the window is seen exactly as if we were looking at it with the naked eye, while in all other positions the image is fainter, and in two positions it disappears altogether.

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It has therefore been proposed to make use of such Nicol's prisms for looking at oil-paintings which are so hung that the light reflected from them is troublesome to the observer. This reflected light can be removed by the prism when held in the proper position.

Light reflected from the surface of a body of water is likewise polarized; and if we look at such a surface through a Nicol's prism, or in a black glass properly placed, this light can be destroyed, and we can then look into the depth without obstruction.

But even the light of the clear sky is polarized, and it must be noticed that both the direction and the degree of polarization are dependent upon the position of the particular piece of sky under observation in relation to the sun. If, therefore, the clear sky is reflected from a quiet surface of water, the same effects must necessarily be produced here with which we have become acquainted above by the use of the black glass. According to the relative position of sun, surface, and observer, the light of the sky may be reflected by the water either completely or partially, or almost imperceptibly.[1] In the latter case the proper color of the water asserts itself, and this is the reason why water sometimes appears of a deep blue or bluish green, even on days when the sky shows very faint, hazy hues. This may be noticed most strikingly when the observer, whose face is turned towards the water, has the sun at his side; while, if the sun be before or behind him, the reflected image of the sky will possess its natural color, and the water will never appear so beautifully and so deeply colored.

Clouds reflect the light irregularly, and consequently impart no polarization to it. The reflection of the light emanating from clouds, therefore, always takes place without obstruction upon a quiet surface of water, and hence, when the sky is overcast, the clearest mountain lake can never show that depth of color which enchants the beholder so powerfully on clear days.

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The extinction of the polarized light of the sky frequently gives rise to very curious phenomena. The author recollects an instance, when, on a beautiful summer evening, with the setting sun behind him, he had at his side a sheet of water upon which were reflected the trees of an avenue. The trees were relieved in a tolerably dark hue from the bright horizon, while in the reflected image, on the contrary, they appeared brightly upon a dark ground. The light thrown back by the leaves in all possible directions exhibited no definite polarization, and the reflected image of the trees consequently differed but little in intensity from the original; but the polarization of the light of the sky in the position just described was such, that its reflection on the water must necessarily be very faint.

39. The black glass. Such abnormal phenomena should admonish the artist to be very cautious in making landscape studies with the aid of the black glass; for the picture seen in it may vary materially from the truth of nature, as in certain positions polarized light will not be reflected by such a glass. An experiment lately made by Professor HAGENBACH, of Basle, shows most convincingly that this caution is not superfluous. The so-called haze, which spreads like a veil over the landscape on warm, calm summer days, especially towards noon, is produced by the reflection of the light of the sun from the particles of air, or perhaps from the particles of water suspended in it. This reflected light is polarized, and can therefore be destroyed by a black glass, or, better still, by a Nicol's prism, as it is much easier to find the proper position with the latter. If we look at the landscape through such a prism, the air will appear transparent, and we can discern details in distant objects, which otherwise would entirely escape our observation. Distant mountain chains which have become invisible through this haze can again be made visible by a Nicol's prism, and it might therefore be well for tourists to provide them-

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selves with such an instrument when ascending mountains, or, still better, to have it fixed to a telescope.

It follows from what has been said that a landscape seen in a black glass appears less hazy than when seen with the naked eye, and this may explain why artists who employ such a glass habitually are apt to fall into a hard and dry manner.

40. The color of the sky. By the observations just made we have been slowly led towards the question concerning the color of the sky. Unfortunately, it is still in great part an open question. This much, however, may be regarded as a fixed fact, that in the case of the sky we are not dealing with an inherent color, such as that of water, but that the color phenomena of the atmosphere are produced in quite a different manner.

Certain it is that the air belongs to a group of bodies which exhibit different colors when the light falls upon them, and when it is transmitted through them; for in light falling upon it, the air appears bluish white, while in transmitted light it appears yellowish red. A thick layer of air before a dark background shows a bluish color when illuminated by the sun; white light falling through the same layer assumes, on the contrary, an orange, and finally a red color. The sun, which appears white when at the zenith, assumes a yellow color as soon as it approaches the horizon, until finally it disappears as a disk of a deep red. The moon also undergoes a similar change of color. The luminous parts of distant objects show yellowish and reddish hues, those in the shadow bluish hues.

In this connection, however, we must not forget that this bluish color is in reality extremely faint, and that phenomena of contrast are largely instrumental in strengthening it. It is very easy to convince ourselves of this, by cutting a small hole into a black screen, and then holding this screen up to the sky at the distance of about an arm's-length from the

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eye. The small piece of sky seen through the opening invariably appears quite faint, almost gray, in color. It is furthermore a fact, which is well known to all better artists, that blue pigments must be used quite cautiously, even in the representation of a deeply blue sky.

If, however, an explanation be now demanded of the color phenomena of the atmosphere, which offer so magnificent a spectacle, especially at sunrise and sunset, the physicist will be compelled to acknowledge that, so far, it is impossible for him to give such an explanation with certainty.[8]

NEWTON assumed that water is present in the atmosphere in the form of very minute bubbles with extremely thin walls, and that these bubbles give rise to colors like the walls of a soap-bubble, or like a film of oil spread out upon water. Following up this theory more in detail, we shall indeed find, that according to this hypothesis blue hues must appear when the light falls upon the bubbles, while yellow hues will be seen when the light is transmitted through them.

Opposed to this view there is another, which owes its origin to LIONARDO DA VINCI. According to the latter the colors of the atmosphere must be classed among the colors of turbid media.

It is a well-known fact that mixtures of two bodies which are in themselves colorless, but which will not mix completely with each other, and therefore appear turbid, show a yellowish-red color when the light falls through them, and a bluish color when it falls upon them, precisely the same as the air. This may be seen very well when milk is mixed with water, or, still better, when an alcoholic resinous solution, such as tincture of benzoin or essence of myrrh, or even only high-proof alcohol, is poured into water. Solid bodies also offer similar phenomena, bone-glass, for instance, which imparts a deeply red color to a flame seen through it, or the precious opal, from which this whole

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group of phenomena has taken its name, to wit, *opalescence*. Artists likewise meet with the colors of turbid media, although only to a very slight degree, in glazing with body-colors, especially with white. A white pigment, dragged over a dark ground in a very thin layer, assumes a slight tinge of blue.

These phenomena, that is to say, the colors of turbid media, which, as is well known, were selected by GÖTHE as the basis for his theory of color, are also still without an adequate explanation.

If, therefore, the colors of the atmosphere are characterized as the colors of a turbid medium, this characterization is still very far from an explanation, for by it these colors have only been classed with a group of phenomena which are themselves as yet waiting for an explanation.

The same conditions as in a turbid medium are at all events present in the air, for the atmosphere contains air and watery vapor, or, in case of great dryness, at least cold and warm air, in a state of continued mixing and moving, similar to the water and the alcohol which have been poured together into one vessel.

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THIRD CHAPTER.

THE THEORY OF THE MIXTURE OF COLORS, AND THE SYSTEM OF COLORS.

41. Difference between mixture of pigments and of colors. ALL the experiments thus far described have shown that pure colors are hardly ever met with in the ordinary course of life, if we except the brilliant chromatic displays exhibited by dewdrops and precious stones. To produce, or rather to eliminate, such pure colors the physicist is compelled to employ artificial devices especially designed for the purpose. The colors seen by us under usual circumstances are the product of the mixture of various monochromatic rays. The results of these mixtures, in simple cases, have so far been supposed to be well known. It has been assumed that a pigment which absorbs or destroys all the rays of white light, with the exception of the red and the yellow, must necessarily show a reddish-yellow color; we have tacitly made ourselves familiar with the idea that indigo in a concentrated solution owes its violet tinge to a small portion of red, etc. But these cases were so simple that our unassisted feeling, and indeed even the usages of language, were sufficient to indicate the results of such mixtures.

In other more complicated cases, however, it is not quite so easy to foretell the result of the mixture of colors, and no part of the theory of color has so long remained in the dark as that of the theory of mixtures. The reason for this is to be found in the fact that no attention was paid to the

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manner in which colored bodies receive their color, and that consequently no difference was made between the mixture of colors and of pigments.

The results obtained by mixing *pigments* upon the palette of the artist were simply transferred to the mixture of *colors*, and the conclusions arrived at were therefore frequently quite erroneous. These erroneous conclusions left a gap in the whole system of the theory of color, and made it impossible to unite the theory of the mixture of colors under one point of view with that of contrasts.

As the mixture of colors and the mixture of pigments in many cases lead to results which are almost identical, while in other cases these results differ completely, the confusion of ideas alluded to is easily explainable, although for the same reasons it is likewise all the more disastrous.

The great merit of having called attention to this point, and of having cleared it up, belongs to HELMHOLTZ.

The question will here undoubtedly force itself upon many of my readers: But how is it possible to mix colors otherwise than upon the palette?

The answer of the physicist will be: On the palette we do not mix *colors* at all, but only *pigments;* to mix *colors* we must employ means of a very different nature. Before, however, describing these methods, it may be well to call to mind a few instances in ordinary life, in which we have to deal, not with the mixture of pigments, but with that of colors.

42. Some cases of true mixture of colors.

If, for example, we spread out a colored veil, the threads of which must be as opaque as possible, upon a ground of another color, the mixture of the color of the threads and of that of the ground seen through the meshes will take place in the eye itself, and we shall therefore see a real mixed color.

If the veil is blue and the ground yellow, we shall see a gray hue. If the veil falls in folds over a dress, the projecting parts of the veil will appear blue, while whitish

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hues will be observable in those places where the veil lies flat upon the ground. A yellow veil upon a blue ground produces similar phenomena; the blue will be dulled, but green will appear under no circumstances.

If an artist, for the purpose of imitating such a combination, were to mix together yellow and blue, he would be totally mistaken. He would produce green, and hence would reach a result entirely different from that which he sought to obtain.

A similar observation can be made when we look at a pattern of fine blue lines upon a yellow ground at a distance sufficiently great to cause the drawing to appear indistinct to the eye. In this case we shall also see, not a green, but a broken gray hue.

Vermilion and ultramarine, mixed upon the palette, produce a dirty reddish brown, with only a faint tinge of purple. But a pattern of fine lines, in vermilion, upon a blue ground, when seen at a distance, will appear of a delicate purple hue. Here again the colors in question are mixed in the eye. If, on the contrary, we apply these pigments to larger surfaces, and then place them alongside of each other, we shall see nothing of a mixture. In that case the contrast will assert itself, and will cause the blue to appear somewhat colder, while the red will assume a more ordinary look, that is to say, more of a brick red. Figs. 3 and 4 on Plate V. will illustrate these remarks.

Figs. 5 and 6, as well as 7 and 8, show similar phenomena; in Fig. 5 the red of the one half is made to look lighter by the fine white lines upon it, while in the other half it is made to appear darker by the black; and, when we compare Figs. 7 and 8, it will hardly be deemed credible that the same blue is present in both cases.

The process of mixing colors by placing surfaces of very small area in juxtaposition is made use of on a large scale in textile industry; in the weaving of shawls, for instance,

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and sometimes also in embroidery, but most of all in the manufacture of gobelins. It would be utterly impossible to produce by dyeing the infinite variety of shades which are needed in the manufacture of gobelins, and the various transitions from one color into the other are therefore obtained by yarns consisting of threads of different colors twisted together. In the case of transitions between light blue and white, for instance, these transitions would be produced by yarns consisting of six blue and one white thread, five blue and two white threads, and so on.

If, during the progress of the work, it is furthermore found necessary to produce such transitions within certain definite limits, the method of hatching (*hachures*) is made use of, that is to say, the workman adds to his threads others of a different hue, so that the whole has the appearance as if the ground were dotted with short lines of a different color. These fine lines, however, can only be seen in close proximity. At the distance for which the work is calculated, nothing can be seen but the effect of the mixture of colors.[9]

In color-printing this method of mixing is also employed, by using what is called a mottled ground. The very rough paper for which water-color painters have a special liking gives rise to similar phenomena. Pigments of a grainy nature have a tendency to fill up the grain of the paper, and the effect produced by these pigments finally blends with that produced by others, which spread out more evenly.

Again, when the artist who paints in oil employs opaque colors for glazing, small particles of the latter are scattered over the surface, and thus give rise to a mixed color. Every artist knows that in most cases the effect is entirely different from that which would be produced if the pigments were first mixed, and were then laid upon the canvas.

Genuine mixtures of colors are also produced by effects of contrast, of which we shall speak more fully in a subsequent

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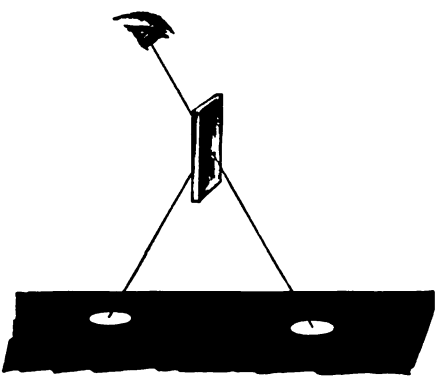
chapter. If, for instance, we place a green surface alongside of a gray one, the latter will assume a reddish tinge by contrast; if, instead of the gray surface, we select a blue (best of all a bluish gray) one, the latter will assume more of a violet tinge; the red produced by contrast simply mixes with the blue of the ground. It is therefore necessary to know the laws of the mixture of colors, before we can pass on to the theory of contrasts.

43 Mixture of colors by reflection.

All the methods, however, which have so far been spoken of as means for the true mixture of *colors*, are insufficient on account of their imperfection. For purposes of investigation we need special apparatus.

The simplest apparatus of this kind (Fig. 24) consists of a piece of clear plate-glass, which is so placed that upon one of its surfaces we see the reflection of a colored surface, while, looking through the plate, we see another surface of a different color. For this purpose colored wafers upon a black ground will answer very well, and such wafers have also been represented in the figure. If we operate in this manner, the variously colored rays emanating from the two surfaces will reach the eye simultaneously. By inclining the plate of glass towards either side, we can vary the proportion of reflected colored light at will. The same result is reached by raising or lowering the head, as the quantity of reflected light is always dependent upon the angle of incidence.

Fig. 24.



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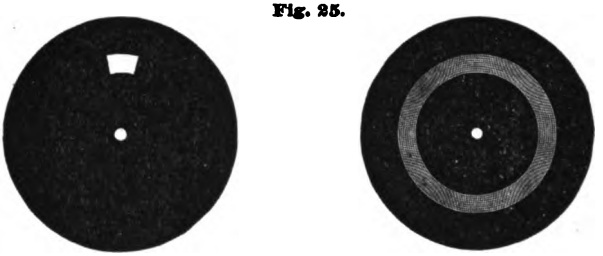
44. Mixture by persistence of impressions. Another method is based upon the so-called persistence of impressions received from light. A burning coal, quickly swung about, has the appearance of a continuous circle. This simple experiment, by which children amuse themselves, may be looked upon as the starting-point for the method now to be described. If we paint a white spot upon a black disk (Fig. 25 *a*), and then cause the disk to rotate rapidly, we shall see a faint white (gray) ring (Fig. 25 *b*). If the rapidity of rotation is

Fig. 25.



a *b*

not sufficiently great, the ring will not appear continuous. The experiment shows that the impression made upon one part of the retina of the eye by the white spot does not cease as soon as the excitation passes on to another part. This impression, on the contrary, continues for some time afterwards; and if therefore the period of rotation of the disk is so timed that the effect of the excitation upon a certain place on the retina has not yet ceased when the same place is a second time exposed to the effect of light, it follows that the impression of light at this place will be continuous instead of intermittent, and that all the places upon the retina so affected taken together will form a bright ring. It is evident, however, that this ring cannot be nearly as bright as the white spot when standing still, since the quantity of light which acts upon one place on the retina when the spot is at rest is now dispersed over quite a number of such

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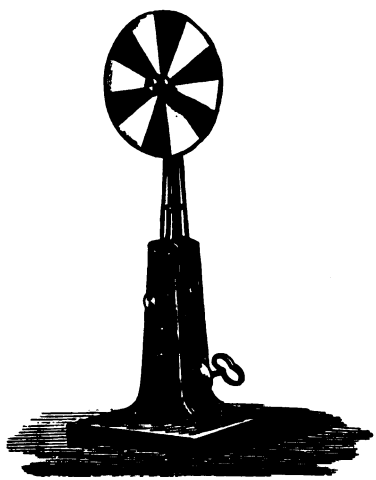
places, and each of these places can therefore receive only a much smaller quantity of light within a given period.

If, instead of a white spot, a white sector had been fixed upon the disk, the latter, when rotating rapidly, would have appeared gray throughout its whole surface, and the broader the white sector the lighter would have been the gray.

In making this experiment it will be advisable to cut the sector into several smaller parts, and to distribute these parts on the disk at equal distances, as shown in Fig. 26. With this arrangement a less degree of rapidity of rotation will be sufficient, as it is only necessary that the impression made by one sector should last until the next white sector takes its place, that is to say, in the case of six equally broad white and black sectors, until the disk has gone through one twelfth of one revolution. If, on the contrary, the sectors had been combined into one, the persistence of the impression would have to continue until one half of one revolution had been accomplished, from which it follows that in the latter case the speed required would be six times as great as in the former.

Fig. 26.



If, instead of the black and the white sectors, we had made use of sectors of various colors, the impressions made by these colors would also persist, and would finally blend together so as to form a mixture.

45. The color-top. To impart the necessary speed to the disk, the latter is put in motion by clock-work, and

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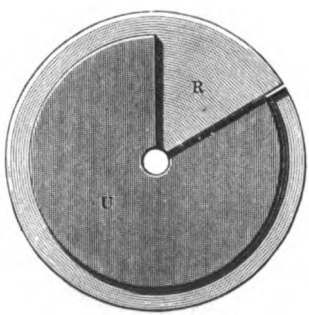
the resulting apparatus is then called a color-top, as it is principally used for the purpose of producing mixtures of colors.[10]

To be able to obtain an exact measurement of the colors to be mixed, the disk upon which the sectors are painted is laid upon another of a somewhat larger size, and having a scale around its circumference. Provided that the speed which can be obtained by the apparatus is sufficiently great, it will, however, be best to employ disks forming perfect circles for each color. If radial cuts are made into these circles, any two of them can be so placed into each other that one will overlap the other more or less, and we shall thus be enabled to vary the proportional quantities of the colors at will. A screw-nut serves to hold the disks tightly together. Fig. 27 illustrates this arrangement, but the upper disk has been represented somewhat smaller than the lower disk, so as to show how the two overlap each other. When the experiment is actually made, both must of course be of equal size. If *R*, in the figure, were red, and *U* ultramarine, we should in this case mix one part of red with five parts of ultramarine blue.

Fig. 27.



46. Mixture of the colors of the spectrum. The method of mixing colors by means of the color-top can only be applied to pigments. If we wish to mix pure colors, we must superimpose parts of several spectra one upon the other. The simplest manner of doing this is to cut two slits alongside of each other in a dark screen, instead of one. If we suppose s_1 and s_2 in Fig. 28 to be these slits, two spectra will be projected upon the screen *S*, which will more or less overlap each other according to the position of the screen. The point

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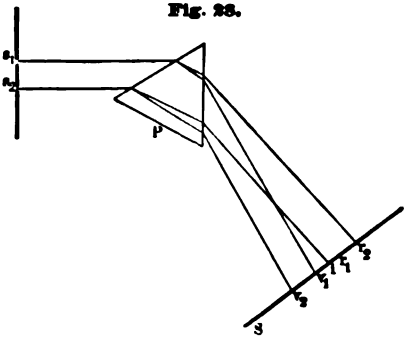
i, for instance (see figure), will receive both the blue and the yellow rays, and must therefore show the color produced by the mixture of blue and yellow. If the experiment is to be made with exactness, care will have to be taken to shade off all the colors with the exception of those which are to be mixed, so as to prevent all interference by effects of contrast. In this case the arrangements to be made will also have to differ from those described, although the principle will remain the same. But it would carry us too far to detail these arrangements here.

Fig. 28.



If it is desired to see all possible mixtures of pure spectral colors at a glance, a V-shaped slit must be employed. We shall then obtain two spectra, as shown in Fig. 29, which will overlap each other.

Fig. 29.

These experiments may also be made without the usual elaborate apparatus by employing very narrow strips of paper instead of the slits, laying them upon a black ground, and looking at them through a prism. But great caution must be exercised in judging of the results thus obtained, as manifold effects of contrast come into play when the method last described is made use of.

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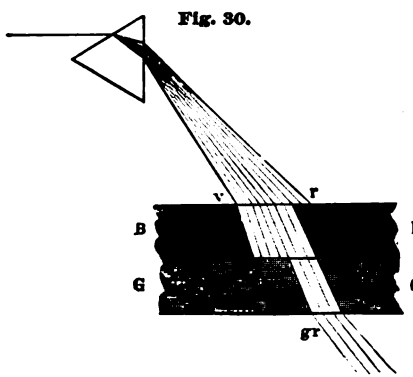
47. Mixture of pigments. We presume that, in the light of the explanations thus far given, the expressions "mixture of colors" and "mixture of pigments" will now be readily understood. The reason why it is possible for these two mixtures to give different results has not yet been discussed. But it will easily be comprehended, if we call to mind the manner in which pigments act.

On Plate I. the spectra of gamboge and of Prussian-blue are represented by Figs. 2 and 3.

As might be expected, the colors of the red end are wanting in one of the spectra, while in the other those of the violet end are wanting. Consequently, if we mix the two pigments, the red and the yellow light which has passed through a grain of gamboge with undiminished strength will be sensibly weakened by the grain of Prussian-blue with which it afterwards comes into contact, and finally, upon the frequent repetition of this process, it will be destroyed altogether. In the same manner the blue light which has passed through a layer of Prussian-blue will be absorbed by the layer of gamboge which follows. It is apparent, therefore, that none but the green rays, and those which are closely related to them, can pass through a mixture of the two colors named, and that such a mixture must appear green in consequence. This will best be understood by supposing a solar spectrum to be projected through a layer of Prussian-blue, and then through another of gamboge. The process which would take place in such a case is illustrated by Fig. 30.

Fig. 30.



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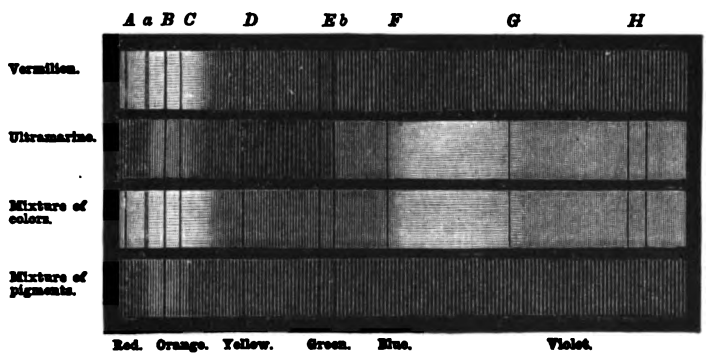
The spectrum of the mixture of the two pigments therefore consists of the rays which are finally left, as shown in Fig. 5 of Plate I. It is evident that the process we are here dealing with is equivalent to the arithmetical operation of subtraction. One of the pigments destroys one part of the impinging rays, the other destroys a second part, and the color produced by the mixture of the two pigments represents the remainder.

If, on the contrary, we mix the colors by reflection, or by means of the color-top, all the rays reflected by both bodies will be received simultaneously by the eye, and the spectrum of the mixture thus obtained must necessarily show all the colors contained in both spectra. This process is therefore equivalent to addition, and it will easily be seen that the result of the mixture obtained by the first process may be entirely different from that obtained by the second.

To facilitate the comprehension of these phenomena, we will add a few other spectra of pigments, and of their mixtures, as well as of the mixtures of their colors.

Fig. 31 shows the spectra of vermilion and of ultramarine,

Fig. 31.



one above the other. If these colors are mixed upon the rotating disk the eye is affected by red, blue, and violet light, as represented by the third spectrum in the figure, and the

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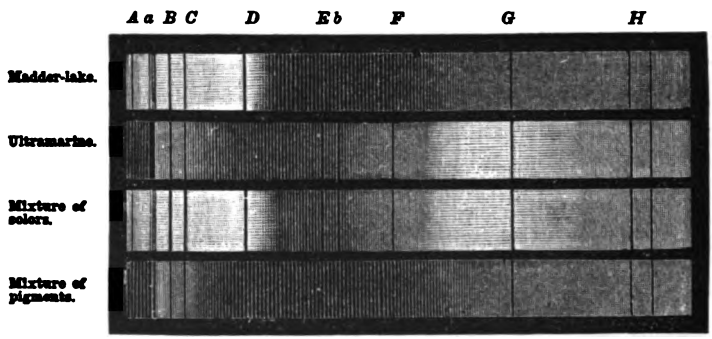
total impression is that of a beautiful purplish violet. If, on the contrary, the pigments are mixed together, or if a layer of the one is imposed upon a layer of the other, the ultramarine will absorb the yellow, the green, and part of the red, while the vermilion, besides yellow and green, takes away also the blue and the violet, so that finally nothing is left but that part of the red which the ultramarine allows to pass, that is to say, a red of a very low degree of luminosity. Such a red, however, is equivalent to reddish brown.

If now, instead of vermilion, we employ madder-lake (of a shade approaching purple), the difference between the results obtained by the mixture of colors and by that of pigments will be far less (Fig. 32). This is explained by the fact that the

Fig. 32.



spectrum of madder-lake, besides red and orange, contains also some violet; and while, therefore, the mixture upon the rotating disk shows a beautiful purplish violet (nearer to violet than that previously obtained), the mixture of the two pigments will also give us a violet, although of a tolerably dark shade, the difference in the results being in quantity rather than in quality.

Under no circumstances shall we be able to foretell the result which will be obtained by the mixture of pigments, or by allowing light to pass through successive layers of

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colored media, unless we have special experience in this respect, or unless we are intimately acquainted with the spectra of the pigments or media employed.

An excellent proof of this assertion is furnished by the following experiment (STRUTT), which is moreover of peculiar interest in other respects. If we place a solution of bichromate of potassium (yellow) and a solution of litmus (blue) one behind the other, and then look through both at a white surface behind them, this surface will appear yellow, and not green, as we are led to expect, and as, indeed, it would appear, if, instead of the solution of litmus, we had chosen another blue fluid, say a solution of sulphate of copper, or of indigo, etc. If now we investigate the light which has passed through both solutions by the aid of the prism, we shall find that it contains *no yellow at all*, but only red and green, while in the place of the yellow there appears a broad dark band. This combination of a blue and of a yellow transparent medium therefore leads to a result which is entirely different from the results ordinarily obtained in similar cases. At the same time we here meet with the very interesting phenomenon of a colored light, in which its apparently dominant color is not represented at all, for here we have yellow light, which nevertheless does not contain a trace of the yellow of the spectrum. The combination appears transparent and yellow, and yet it is impenetrable to the light of the yellow sodium flame. Such experiments very strikingly exhibit our inability to tell the composition of a mixed color without further investigation, and they are likewise admirably well calculated to illustrate how it may happen that two pigments of the same appearance may be entirely different in their photographic effect.

It will now be sufficiently clear that the result of the mixture of pigments cannot be told beforehand, without previous investigation, and that experience is our only guide in this matter. With the mixture of colors, on the contrary, it is

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different. For the latter simple laws can be laid down, and with these laws we shall now have to occupy ourselves. It is self-evident that our investigations must primarily be conducted with *pure* colors, that is to say, with the colors of the spectrum.

48. White is a mixed color. It was shown in the first chapter that the white light of the sun, or daylight, may be resolved into the colors of the spectrum, but that the latter can be resolved no further. From this premise we came to the conclusion that innumerable colored rays must be present alongside of each other in white daylight, and that therefore white light must be a mixture of all the colors of the spectrum. By mixing these latter we must consequently be able to produce *white*, if our conclusion is correct.

This is really the case. The very simplest proof is found in the fact, already alluded to, that pure spectra can only be obtained by means of very narrow slits or strips of paper, while a broader slit gives a white image, which is colored only at its edges. A broad white strip of paper, looked at through a prism, similarly appears white with colored edges. A simple diagram will suffice to give an insight into this experiment which was so long misunderstood, and the erroneous interpretation of which was the sole reason for GÖTHE'S polemics against NEWTON.

If we suppose that there are two slits, s_1 and s_2, Fig. 33, in the shutter, instead of one, and that spectra are projected from them upon the screen S, these spectra, the ends of which are represented by r_1 and v_1, r_2 and v_2, will partially overlap each other, and all points between r_2 and v_1 will therefore be illuminated by light of two different colors. If now we add a third slit, each point between r_3 and v_1 will receive three kinds of differently colored light; with four slits, each point between r_4 and v_1 will receive four kinds, etc.; so that, if the number of slits situated between s_1 and s_4 is gradually increased, the points lying between r_4 and v_1 will show the

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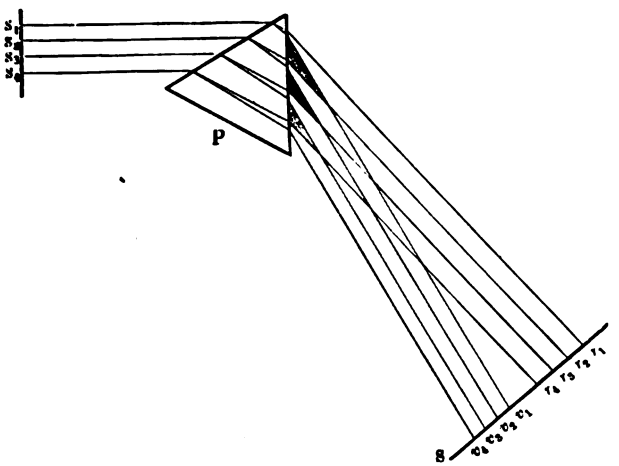
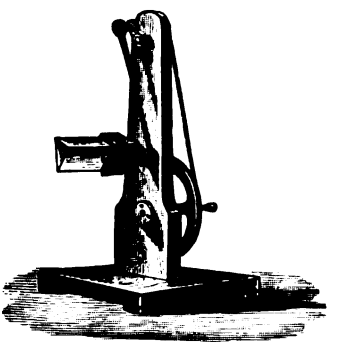
results of the mixture of a constantly increasing number of simple colors. If, finally, we conceive the number of individ-

Fig. 33.



ual slits to be increased to infinity, so that all these slits run into each other, and blend into a single one of the width $s_1 s_4$, the points in question will receive light of all the colors of the spectrum, and must therefore appear white, which is really the case.

Fig. 34.



Should this simple experiment be deemed insufficient as a proof, the same principle may be demonstrated by still other means. An apparatus constructed for this purpose is represented in Fig. 34, and the manner in which it operates is illustrated by the diagram, Fig. 35. A prism with horizontal edges is so fixed upon an axis and attached to

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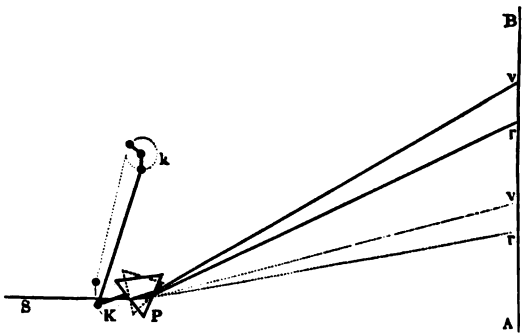
a crank which is set in motion by means of a pulley and belt, that the prism, when the crank is turned, executes ex-

Fig. 35.



ceedingly rapid oscillations within moderate limits. If with this prism we project a spectrum upon the screen *A B*, the spectrum, in consequence of the oscillations of the prism, must move up and down very rapidly upon the screen. All the points situated between the highest position of the red (*r*) and the lowest of the violet (*v*) must therefore be struck twice by all the rays of the spectrum during a single oscillation of the prism; and as the image of this continually changing illumination, on account of the persistence of impressions of light, must blend together into one total impression, this latter must necessarily be that which is produced by the mixture of all the spectral colors. This is again the case, for the path travelled over upon the screen by the spectrum during the oscillations of the prism appears white, the two points of termination only being colored, as at these points a mixture of all the colors of the spectrum is no longer possible.

A third method of producing white by the mixture of the colors of the spectrum will be described shortly, upon a somewhat different occasion.

These experiments therefore demonstrate the following

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proposition: *All the colors of the spectrum of the sun, or of daylight, when mixed together, produce white.*

The same proposition may also be demonstrated by the aid of the color-top, although somewhat imperfectly, as on the one hand it is impossible to imitate the colors of the spectrum by pigments, while on the other a great part of the light falling upon the color-disk is destroyed by the peculiar manner in which the pigments operate. If, therefore, we imitate the colors of the spectrum as well as we can upon the sectors of the disk, and then cause the latter to rotate, we shall obtain *gray*, that is to say, white of a low degree of luminosity, as the result of the mixture. It follows that even these imitations of the colors of the spectrum produce white, but this white cannot possibly be equal in brightness to that emanating from a disk of white paper, as only a small part of the light falling upon the disk is reflected back from it. Still, by employing a little artifice, we can nevertheless make the disk appear white while rotating. To reach this end we must take care that it is relieved from a dark ground in an intense light, and that all white objects of comparison are kept out of sight.

49. Complementary colors. The experiments on pigments have shown to us that we obtain a colored mixture whenever any of the individual constituents of white light are removed from it. In the cases with which we have had to deal thus far this removal was executed by colored bodies. In all these cases, however, we were unable to destroy at will any given group of rays, for we were entirely dependent upon the nature of the pigment employed. This dependence may be completely obviated by first decomposing white light into its constituent elements by means of the prism, and then reuniting only partially the simple rays thus obtained.

The experiment may be conducted as follows: —

The fan of prismatic rays, which emanates from the prism *P*, Figs. 36 and 37, is caught up in its whole breadth by a

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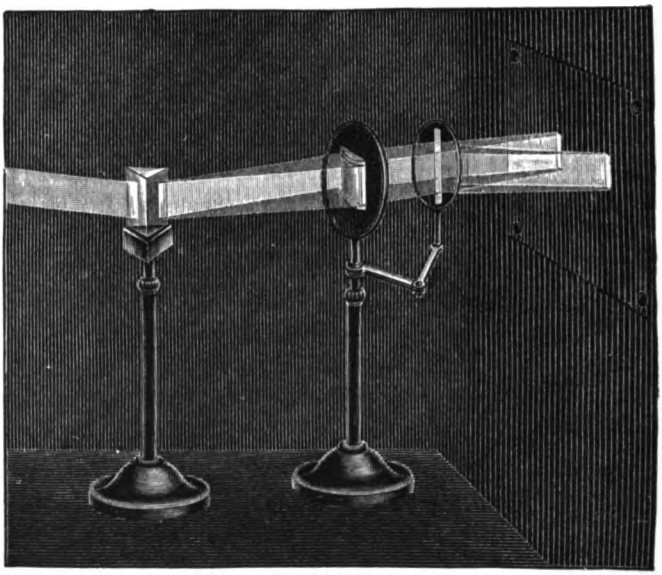
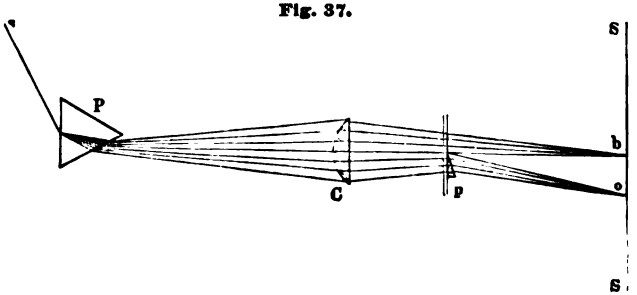
cylindrical lens, that is to say, a lens which is bounded by cylindrical surfaces. It is the peculiar property of such a lens

Fig. 36.



that it reunites the prismatic bundle of rays into a single band, the image of the slit. This image, which is seen upon

Fig. 37.



the screen at the point *b*, is of course colorless (provided that the apparatus at *p* has been omitted), and offers another proof

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of the correctness of the proposition, that a mixture of all the prismatic rays produces white.

If we now introduce a screen at any point between C and b, say at p, the image of the slit b will immediately appear colored, the color varying according to the colors which have been cut off by the screen. If we suppose the red to have been removed, the image at b will appear bluish green; if the yellow has been taken away, it will appear blue, and so on.

But the experiment may be made much more interesting and instructive by employing an exceedingly narrow prism of a very acute angle instead of the screen. Such a prism, which exceeds the blade of a penknife in fineness, and which must therefore be cemented to a plate of glass, shows no sensible dispersion of colors, while its power of refraction nevertheless asserts itself. By the aid of a prism of the kind described we can therefore divert part of the rays emanating from the cylindrical lens towards one side, and from the rays so diverted we shall also receive an image of the slit, but at a. Both of these images are colored. But,

If a is red,	b will be bluish green.
" a is orange,	b " " turquoise-blue.
" a is yellow,	b " " ultramarine-blue.
" a is yellowish green,	b " " violet.
" a is green,	b " " purple.

The artist will immediately recognize the pairs of contrasting colors which are so well known to him.

But the experiment just made has taught us that these pairs of colors are those which will produce white if mixed together. We therefore say that these colors *complement* each other, or, in other words, that they produce white with each other, and hence we call them *complementary colors*. It is self-evident that all the methods of mixing colors, which have previously been described, can be applied to these pairs, and that the correctness of the last proposition can therefore be proved in various ways. But it must never be forgotten,

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in making these experiments, that all mixtures obtained by means of the color-top can only produce white of a low degree of luminosity, that is to say, gray, as each of the pigments employed absorbs a part of the white light.

50. The system of colors. It was necessary to go through these introductory experiments, to enable us to bring into a system the sum total of all the sensations of color of which we are capable. But before we can proceed to the construction of such a system we must furthermore endeavor to make clear to ourselves the various modifications which each individual color can be subjected to *without change of hue.* These modifications are so obvious that they have found expression even in the ordinary usages of language. Taking green as an example, we speak of *dark* green, of *full* green, of *light* green, and of *pale* green. We also meet with the term *broken* green, especially among artists.

Now, what is the meaning of all these various designations? How shall we be able to define them unmistakably, and to reduce them to a system? The answer to these questions, at least as far as *dark, full, light,* and *pale* are concerned, will be most readily supplied by the following experiment:—

Let us suppose a surface of intensely green color, say a square painted with emerald green, to have been attached to a white wall in an otherwise completely darkened room. If now we admit the light of day very gradually, beginning with a small opening in the shutter, covered by a piece of ground-glass, we shall at first perceive only a black square upon a gray ground. Increasing the brightness of the illumination somewhat, we shall be able to recognize the color as green, although it will appear to be of a *dark* shade. Increasing the brightness of the illumination still further, we shall also see the green increasing in strength, until finally, in the full light of day, the maximum of the impression will be reached, or, in other words, until we shall see the green in its *full* strength and purity. But if the illumination is carried still

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further, if we allow the direct light of the sun to fall upon the colored surface, the color will again suffer, and after passing through *light* green shades, it will begin to appear *pale* and whitish. The same effect of a pale or whitish color can also be obtained by covering the green surface by a thin white veil, or, which is the same in this case, by an admixture of white.

From the experience which we have thus gathered we may now define the various terms in question as follows: —

A *dark* green is a green which is illuminated by light of a low degree of luminosity, or, in the case of a pigment, which reflects but little light.

A *full* green is a perfectly pure green, illuminated by light of a mean degree of brightness.

A *light* green is a green which is illuminated by light, the brightness of which is so excessive as to dazzle the eye, or it may also be a green mixed with white.

A *pale* green, finally, might be defined as white light with an admixture of green, as the white in it predominates largely over the green. The same effect may be obtained by an illumination of still more excessive brightness.

Dark and full colors are therefore always *pure*, that is to say, they are simply green, blue, red, etc., and free from all admixture of white light, the only difference among them being the degree of brightness.

Light and pale colors, on the contrary, *may* be pure, as the impression produced by them may be the effect of excessive brightness, but under ordinary circumstances they may be defined as colors diluted with white.

The last of the terms alluded to above, that is to say, *broken* green, remains to be defined. By broken colors we understand those colors which reach the eye mixed with faint white, that is to say, gray light, but in which the specific character of their hue is still expressed with tolerable decision. If the gray predominates to such an extent that we

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receive only a very slight sensation of color, we speak of a gray with the addition of the name of a color, such as greenish gray, bluish gray, etc.

An experiment similar to the one made with emerald-green might also be made with vermilion. If we expose a vermilion surface to light gradually increasing in intensity, it will appear brighter and brighter, until finally, in the full light of the sun, it assumes a somewhat whitish appearance. By spreading a white veil over the surface, or by mixing white with the vermilion, we shall obtain a *pale* red.

The fact that all colors grow light, and finally pale, when the degree of brightness exceeds certain limits, can best be observed by looking through pieces of strongly colored glass, at first towards a white surface, and then at the sun, or by gradually increasing the degree of luminosity of a spectrum. The flame of a colored light looks whitish, compared with the objects which it illuminates; a landscape in the full light of the noonday sun falls far short of the beauty of coloring with which it delights us in the morning, or in the evening, etc.

Very *bright* colors are therefore always more or less pale and whitish, but *light or pale* colors need not be bright *because* they are light or pale.

From all this it follows that *brightness* and *purity*, that is to say, the greater or less admixture of white, are variable elements, which may modify the impression made upon us by a color, although they do not destroy its fundamental character, or that which is called its hue.

The intensity of a specific impression of color, its so-called *fulness*, very naturally also depends upon purity and brightness combined; for, as we have seen above, a color may be pure, and yet not full. Provided that the degree of brightness be the same, the purest colors, that is to say, those of the spectrum, will therefore produce the impression of the greatest fulness, and these again at the mean degree of brightness.

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There are a few colors, however, in the case of which we might almost be led to believe that these variations of brightness, which, as we have said, do not influence the *hue* of the various colors, did, after all, exert some effect in this very respect, as, for instance, in the cases of yellow and of violet. Yellow of a very low degree of luminosity appears *brown;* and violet, which is very brightly illuminated, or which is mixed with white, we call *lilac.* But in these cases we are in reality only dealing with peculiarities of language.

Yellow asserts its characteristic hue best of all at a very *high* degree of brightness, violet at a very *low* degree, while for all other colors a medium degree is the best. In the case of the latter colors variations in brightness therefore only occasion oscillations playing about the mean of the specific impression, while in the case of yellow and violet, which represent the two extremes in this respect, the changes are so great that language has invented special names for the modifications seen at the opposite extremes.

The folds of yellow drapery will show that very dark yellow appears brown. Of the fact that brown appears yellow in a very bright light we can best convince ourselves by allowing the light of the sun to fall upon a brown surface through a small aperture. Under such circumstances the small spot so illuminated will appear intensely yellow.

If we now allow all the various sensations of color of which we are capable to pass before our mind's eye, and if we imagine each one of them to have passed through the different shades just detailed, we shall soon discover that every color (hue) has its representative in the spectrum, with the exception of only one, presently to be mentioned, and of white and black, which indeed are not colors at all in the true sense of the word. The exception alluded to is *purple,* the color of the peony, and of rose-madder in thick layers. It is also magnificently represented among the dyer's colors by the aniline preparations known as Solferino and Gari-

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baldi red, sometimes also as amaranth-red. These colors have no representative in the spectrum, and can only be obtained by mixing the hues of the two ends of the spectrum.

All other sensations of color we can conceive of as being produced by the colors of the spectrum, of the proper degree of brightness, with or without the admixture of white.

The colors of the spectrum are the standards according to which all colors are named. The physicist says of all colors (shades, tints) which may be produced by mixing any one of the colors of the spectrum with white, or by subjecting it to all possible variations of brightness, that they are of the same *hue*.

Given the *hue*, the degree of *brightness*, and the degree of *purity*, that is to say, the proportion of pure color contained in the mixture of a spectral color with white, and we have all the elements needed for the unequivocal determination of a color.

The three elements just named (hue, brightness, and purity) are capable of measurement, and can be expressed by figures. A detailed examination of the manner in which such measurements are executed would, however, be out of place here.

It should be remembered that the terms "light" and "dark," as used throughout this paragraph, are to be understood as applying to the variations which any one individual color may be made to undergo. The same terms are sometimes applied to differences noticeable between different hues. Thus we speak of blue as a dark color, of yellow as a light color. It would be better, however, to call yellow a brighter or a more luminous color than blue, and *vice versa*. (See p. 117.)

51. The color-chart. The fact that all colors are represented in the spectrum, with the exception of the purple hues, while these latter form the connecting link between the colors at the ends of the spectrum, has led to a very interesting, and

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withal practical geometrical representation, which was first given by NEWTON.

Inserting the purple hues between the violet and the red, we can place all the colors of the spectrum upon a line which runs back into itself, the passage from one color into the other being brought about by imperceptible transitions. It follows, therefore, that we can also represent them upon a closed line, that is to say, upon the circumference of a circle. If, furthermore, we place the white at a point within this line, we shall be able to represent all the transitions between white and the colors represented at the circumference upon straight lines connecting this point with the outer line of the circle. We shall then have a chart in which all hues of color and all degrees of purity will be represented, and which, when illuminated more or less intensely, that is to say, at different degrees of brightness, will contain within itself the sum total of all our sensations of color.

At the same time the pure colors at the circumference (in the case of a color-chart executed in pigments the purest possible colors attainable) can be so arranged that those colors will always be opposite to each other, which, when (optically) mixed in proper proportions, will produce white (see Plate II. Fig. 1); and in such a chart we shall then possess not only a clear representation of the sum total of all sensations of color, but also a means by which we shall be enabled to determine the results of mixtures beforehand. Having given to the colors at the circumference the proper degree of brightness, we may now find the result of the mixture of any two given colors upon the chart in the following manner: —

Find the places occupied upon the chart by the two colors which are to be mixed, and unite the two points by a straight line. The color produced by the mixture will invariably be found upon this line, and it will be situated exactly in its centre, if the colors are mixed in quantities which are equal to those contained by equally large pieces of the chart, or, in

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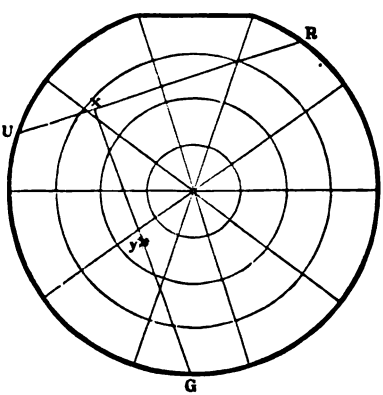
other words, if we divide the rotating disk into two halves, and paint each half with one of the two colors to be mixed. In this case the degree of brightness of the mixture obtained will be equal to the *mean* of the brightness of the two colors which have been mixed. If, however, the mixture is produced by optically superimposing the two colors upon each other it will be equal to the *sum*, that is to say, twice as great as in the first case. On Plate II. the latter method has been assumed. If the quantities are unequal, so that the two colors occupy areas of unequal extent upon the rotating disk, the mixture sought for will indeed still be found upon the connecting line; but instead of being situated in the centre of this line it will be nearer to the color which predominates. The distances of the point at which the mixture will be found from the two ends of the line will be in the inverse ratio to the quantities of the colors to be mixed.

If, for instance, we mix three parts of ultramarine-blue with one part of red, that is to say, if we paint one quarter of the disk red, the other three quarters ultramarine-blue, we can see at once, by reference to the color-chart, what hue will appear when the disk is rapidly rotating. All that we need to do will be to draw a straight line from the point *U* upon the color-chart (which is here given once more in simple outlines, Fig. 38) to the point *R*, and to divide this line into four equal parts. The result of the mixture *x* will be found at the first point of division from *U*. The chart here shows a pale bluish violet, and the direct experiment with the color-

Fig. 38.



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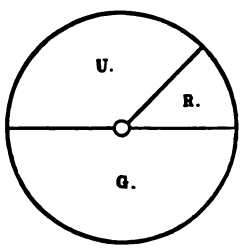
top will convince us that this is indeed the color obtained by the mixture. Let us now suppose that a third color is to be mixed with the two already named, this third color to be green, and the proportion to be four parts of green to the one part of red and the three parts of ultramarine. In this case it will only be necessary to connect the point x with the point G, the latter being the point at which the green is situated on the chart, in order to find the result of the mixture. According to the proportions assumed the mixture will be found at y, exactly in the centre between x and G, as the mixture of one red and three ultramarine, that is to say, of four parts, is equivalent to the four parts of green. At the point y of the color-chart we shall find bluish-greenish white, which must be the color obtained by mixture. This again can be proved by applying the three colors to the color-disk, as shown by Fig. 39, and then causing the disk to rotate rapidly.

52. The law of mixtures. These examples will be sufficient to give a general idea of the manner in which the color-chart may be used for the purpose of determining the result of a mixture of colors. In strict terms, the method may be formulated as follows: —

Fig. 39.



If it is desired to find on the color-chart the result produced by the mixture of various colors when mixed in given proportions, the colors in question must be conceived of as weights, inserted at the corresponding places of the chart, and the centre of gravity of these weights must be ascertained. The color found on the color-chart at this point is the color produced by the mixture. Two colors which occupy equal areas upon the color-disk must always be given equal weights, while, if the areas are unequal, the proportion of the weights to each other must be the same as the proportion of these areas.

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If the mixture is to be executed by means of colored threads, the weight of each color will be expressed by the number of the threads, provided that the latter are of equal thickness.

When mixing colors which differ in brightness from those here represented upon the chart, we can still make use of the same chart to determine the results of mixtures, but we shall have to proportion the weights according to the degrees of brightness. This will easily be understood after having considered the following points: Let us apply one of the colors found on the chart to one half of the rotating disk, and let the other half be covered with pure black, of which latter we will assume (although the assumption is not quite correct) that it absorbs all the light falling upon it. If we now cause the disk to rotate, the light which is reflected by the colored half will evidently be distributed over the whole of the disk, and any given piece of the disk, while in motion, will therefore send only one half the amount of light into our eye which would be sent into it by an equally large piece of a disk painted all over with the same color. It follows that the disk will appear only half as bright. Instead of a certain quantity of a color of a less degree of brightness, we may therefore employ a smaller quantity of a brighter color, and we can then make use of the same method as before for the purpose of finding the result of a mixture. It is self-evident, however, that in such a case the mixture obtained will possess a lower degree of brightness than the color found at the corresponding point of the chart.

53. The cone of colors. But although the color-chart represents all conceivable sensations of color, provided the white light by which it is illuminated can be varied through all gradations from the full light of the sun to complete darkness, it will nevertheless be much more desirable to find a representation which contains the colors in their various degrees of brightness, while the light illuminating it remains the same.

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This end may be reached by designing a number of other color-charts in addition to the one already described, all of which charts will have to be constructed exactly like the first, and will differ from it only by a less degree of brightness.

If we were to execute ten such charts, arranged in succession, the first possessing nine tenths, the second eight tenths, etc., of the brightness of our original chart, the last would finally be equal to zero, that is to say, it would have to be painted black. As the brightness of these charts decreases, the number of hues to be discerned upon them will likewise decrease, and it will therefore be well to make the darker charts of smaller dimensions. Having really executed these charts in such a manner, and having taken care to proportion their diameters to the degrees of brightness of each, we can now build them up, one above the other, and at equal distances from each other, and we shall then find that their boundary lines are all situated upon the outer surface of a perpendicular cone.

If now we conceive the number of these color-charts to be increased to infinity, so as to fill the whole of the cone, it will be seen that this cone must contain all the hues which may be obtained between black on the one hand, and the lightest colors represented upon the lowest chart on the other.

Within such a cone we can therefore find a place for all the hues which we can conceive of, and which our eye is capable of perceiving. Upon its outer surface the cone will contain nothing but perfectly full colors in their various degrees of brightness, that is to say, in all transitions from the greatest brightness to complete darkness, or to black, which latter will find its place at the apex of the cone. If such a cone is really constructed with the aid of pigments, the very outermost surface which contains the colors of the spectrum, or, in other words, absolutely pure colors, will of course have to be added in our imagination, as even our strongest pigments are still far removed from absolute purity.

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The disposition of the hues upon the surface of the cone is illustrated by Fig. 40. Fig. 2 of Plate II. represents the same surface, seen from above (with this difference, however, that the transitions between the ten hues there represented have been omitted); Fig. 41 shows the ground-plan, which is also found in Fig. 1 of Plate II. (subject to the same qualification as Fig. 1); Fig. 42 presents a horizontal section through the cone, executed at the distance of one third from the apex. In reality this section ought to have been drawn in smaller dimensions, but it has been made somewhat too large in proportion, as otherwise the words inscribed in it would no longer have

Fig. 40.

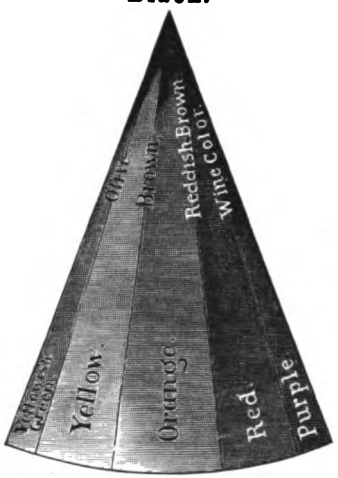


Fig. 41.

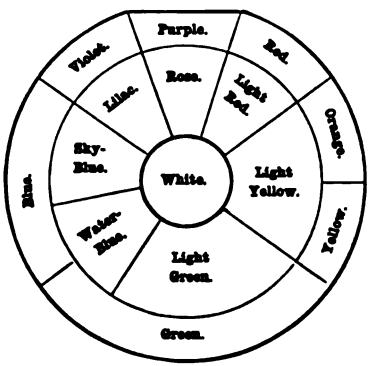
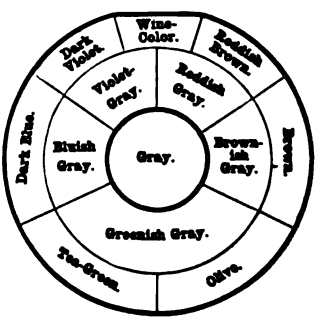


Fig. 42.



been readable. Imagining these sections to be increased in number, we shall see at once that the axis of the cone con-

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tains all gradations of neutral gray, from the brightest white to the most intense black. Between the axis and the outer surface, on the contrary, there will be found the *pale* and the *broken* hues, the various kinds of gray being grouped around the axis, while the colors of more or less dulness are situated toward the surface. As regards the designations inscribed in the figures, the author is quite well aware that they are not those used by artists. They were nevertheless chosen, as it appeared necessary to find short words, and at the same time such as would generally be understood.

The law of mixtures, as applied to the cone of colors, will now be found to be the same as in the case of the color-chart. In the cone, as well as in the chart, the straight line connecting any two given points contains all the colors that can be obtained by the mixture of the colors situated at these points, and the place at which the mixture is situated is determined as above by finding the centre of gravity.

The correctness of this process may again be verified by means of the color-top, as in the case of the color-chart. A number of small differences will indeed be observed, when making this verification, but as they are of slight importance we can pass them over, with the exception of one, which is tolerably pronounced. It is a curious fact that mixtures of ultramariné-blue and white change somewhat in hue, and show an inclination towards violet. As no satisfactory explanation of this phenomenon has as yet been offered, we must content ourselves with having alluded to it.

54. Significance of the system of colors.

The question has no doubt occurred to many of my readers during this necessarily somewhat dry discussion, whether there is any practical value in such a representation of the system of colors on a chart, or, more comprehensively, in the shape of a cone.

The most beautiful pictures were painted, the most magnificent carpets were woven, and the richest wall-papers were printed at a time when there was as yet no thought of a color-

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chart or of a cone of colors; and thousands of persons are still occupied with art and art-industry of whom certainly only the very smallest part has any idea at all of the existence of such theoretical systems.

But this conventional representation of the system of colors, and of the law of mixtures, which has just been explained, is nevertheless worthy of special and detailed investigation; for it will be found to be the indispensable basis, as soon as it is desired to arrange under simple points of view the mass of individual experiences in the department of the combination of colors, which every devotee of art is compelled to acquire in the course of time.

It is, for example, the foundation of the theory of contrasts, a chapter the eminently practical importance of which will certainly be disputed by no artist. The consideration of the law of mixtures is furthermore of the greatest interest when judging of the worth or the worthlessness of certain æsthetic theories which are based upon the analogy between colors and sounds, and it is finally possible to define colors rigorously and unequivocally by means of the representation alluded to. How very desirable it is to be able to do this, even for practical purposes, may be learned from the fact that the French chemist CHEVREUL, who, for a long number of years, was the director of the dye-works connected with the manufactory of gobelins at Paris, undertook to carry out such a classification of all the hues of color in a work containing above nine hundred quarto pages, and accompanied by a magnificent atlas printed in colors. For this purpose he does not, however, make use of a cone, but he conceives the colors to be inscribed in a sphere. His system is unfortunately based upon arbitrary assumptions, and not upon the true law of mixtures, so that it is impossible for his color-circles to give a deeper insight into the theory of color, and to reveal those laws for the better understanding of which we have just discussed the color-chart and the cone of colors. But at all

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events it will be well to have called attention to the fact that the want of such a system has before been felt on the part even of practical people. Chevreul's color-sphere has been executed in wool in the manufactory of gobelins at Paris, and his system forms the basis of the terminology there in use.

But instead of devoting further attention to general considerations of the worth or the worthlessness of such representations of the color-system, it will be better to pass on to a more detailed inspection of the one here chosen (which owes its origin to the German mathematician, LAMBERT, an Alsacian, who lived in the last century), and to endeavor to draw conclusions from it.

First of all we shall be able to comprehend, by the aid of our representation, the proposition above formulated, that every conceivable sensation of color may be designated by its *hue*, its *purity*, and its *brightness*. For it is easy to understand that no color can be thought of which does not find its unequivocally fixed place in the cone described. But by this place the three characteristic factors just mentioned are likewise fixed.

If we suppose the cone to be divided into compartments by planes intersecting its axis longitudinally, each compartment will contain only those colors which can be obtained by mixing the color situated on the corresponding section of the outer surface with black or with white. The compartment therefore determines the species of the color, that is to say, that quality which, according to MAXWELL, is called the *hue*. The height of the point above the ground-plane determines the *brightness*; while, finally, the distance from the axis of the cone, as compared to the radius which may be drawn through this point parallel to the ground-plane, determines the *purity*. Down the axis will be found only neutral gray, on the surface only pure (full) colors, between the two, as a natural consequence, all intermediate hues in all conceivable degrees of purity.

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By its position in the cone of colors a hue can therefore be easily designated. If, for instance, a reddish gray be given, and if we find its position to be in the red compartment on a horizontal plane which is situated at two thirds of the height of the cone from its basis, while its distance from the axis is equal to one half of the radius of the circle in question, this color would have to be designated as "red of the purity one half, and of the brightness one third," and the same color would be obtained by mixing upon the color-top one part of red with one part of white (in reality light gray), and four parts of black. But we must also obtain precisely the same result by mixing one part of pale red, such as we find it on the ground-plane in the centre of the radius which extends toward the red, with two parts of black; or three parts of red with one part of bluish green and eight parts of black, etc. In short, an infinite variety of combinations can be found by the aid of the law of mixtures, all of which must lead to the same result. The correctness of the law of mixtures can be tested by making experiments with a number of these combinations.

55. Examination of the color-chart. The examination of the color-chart and of the cone of colors under another aspect will, however, be of much greater general interest than the rigorous definition of colors, for this definition is of special importance to only a few of the industries in which colors are employed.

The color-chart, as we have previously observed, has been so constructed that complementary colors are placed opposite to each other, and the degrees of brightness have been so chosen that equally large spaces, that is to say, one half of the disk of the color-top, must be allotted to each of the colors which are to complement each other so as to produce gray or white when the disk is rotating. Strictly speaking, an infinite number of pairs of colors ought to be recorded upon the color-chart, since the colors which find their place

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upon its circumference form an unbroken sequence running through all possible transitions, and the ideal chart which we must construct in our imagination for facilitating theoretical speculations will indeed have to be conceived of as containing all these pairs.

For practical execution with real pigments we shall, however, have to content ourselves with a less number of hues.

We must therefore imagine the ideal color-chart to be covered by a network of lines of division, such as would be left if the lines $U\,R$ and $G\,X$ were erased in Fig. 38. The several compartments obtained in this manner must then be evenly painted with the color which in truth ought to find its place in the centre of gravity of the respective compartments. (See Plate II. The ten hues contained within the outer division of the circles represented on this plate are those here alluded to. It must be borne in mind, however, that the colors available in chromolithography can never equal those of the spectrum. Compare also the description of Plate II.) A double advantage is gained by such a division of the chart into a few hues sharply separated from each other; for thus we not only render the color-chart perceptible to our senses, while otherwise it exists simply as a theoretical fiction, but we shall also find it an easy matter now to name the various hues, and thus to arrive at a mutual understanding of the subject.

As a first result of this method of division, in which we have followed HELMHOLTZ, we shall obtain the five pairs of complementary colors before alluded to, but which we will repeat here once more:—

Purple — green.
Red — bluish green.
Orange — turquoise-blue.
Yellow — ultramarine.
Yellowish green — violet.

The distribution of these hues upon the circumference of

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the color-circle, although arbitrary within certain limits which we cannot stop here to define, has been so arranged that to each of them an equally large space is alloted upon the color-chart.

We will now proceed to examine somewhat more attentively those hues which are situated alongside of each other on the circumference of the chart. Upon making this examination we shall find that in the case of yellowish green, green, and bluish green, for instance, the perceptible difference in hue, that is to say, in the specific character, of each pair of adjoining colors is about equally great. The step from yellowish green to green appears to be about the same as that from green to bluish green.

The same observation will apply to other parts of the color-chart; the step from violet to purple will also appear to be about equal to that from purple to red.

But if, on the contrary, we compare the step from purple to red with that from green to bluish green, we shall find that the former is decidedly much greater than the latter.

While it might appear, from the examination of only three colors which adjoin each other in the scale, that the step from one color to the next is always equally great, we shall find that this conception is erroneous as soon as we extend the examination to all the hues of the circle. In this case we shall discover that in the lower part of the chart, that is to say, in the neighborhood of green, the step from one color to the next is always much smaller than at the opposite side, that is to say, in the neighborhood of purple.

While yellowish green contrasts but little with green, green with bluish green, and bluish green with turquoise-blue, the differences between the complementary colors, violet, purple, scarlet, and orange, will be found to be very considerable. Yellowish green and bluish green will, under all circumstances, be looked upon by an unprejudiced eye as varieties of green, while their two complementaries, violet and red (ver-

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milion, scarlet), differ so widely from each other, that, to our judgment, they appear to be two entirely independent colors.

In other words, it may therefore be said that *very minute changes in the hue of green necessitate very considerable changes in the hue of its complementary*, and this may be one of the reasons why it is so very difficult to employ green artistically.

The bright green of field and forest, which is so refreshing to the eye of the wayfarer in spring, is a very dangerous rock for the artist. The sunburnt Roman campagna, or the autumnal landscape, the leaves of which have been withered by the heat of summer and the early frosts, furnish much more promising subjects for imitation. Even in the decorative arts green does not play nearly as prominent a part as red and blue, — a circumstance which may perhaps be explained, in part at least, by the fact that slight changes in the illumination, and the variations in the hue of the green which are induced by these changes, necessitate great changes in the hue of the complementary color, thus destroying the harmony of the colors combined with the green.

Still another circumstance must, however, be considered, which tends to increase the difficulties encountered in the employment of green, especially by the artist (painter). We shall see in a subsequent chapter that there is a peculiar advantage in dividing all colors into two groups, which will then be opposed to each other as contrasts (see p. 231, *et seq.*), or, in other words, in cutting the color-chart into two halves. This division must be made along the straight line which bounds the purple at its left and the green at its right side. The one half will then contain the so-called *cold* colors, with turquoise-blue as a mean, the other the *warm* colors, with orange for its pole. White and all the very pale colors which are closely allied to it must be counted among the cold colors.

The boundary between these two groups (that is to say, in the *ideal* color-chart containing all the transitions from one

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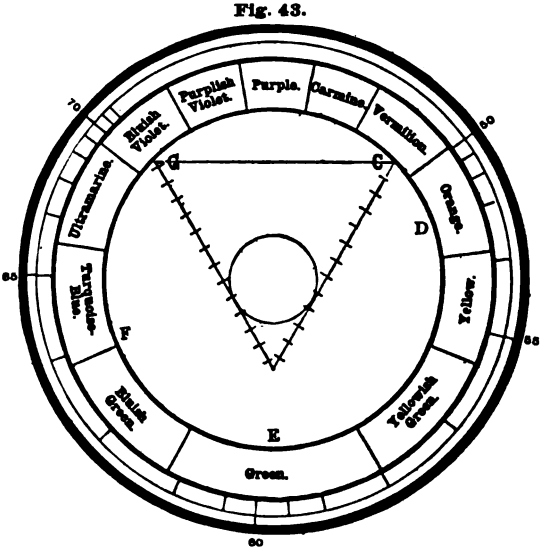
color to another) is formed on the one side by a yellowish green, about the color of leaves, and on the other by a purplish violet. These two colors, together with the hues in their immediate neighborhood, can therefore be employed only with difficulty in a painting, the coloristic composition of which is essentially based upon the division into warm and cold colors. They are consequently found but sparingly in the paintings especially of the Dutch artists, as these artists carried out the principle just alluded to more strictly than any others.

56. The color-chart of twelve divisions.

But let us return to the division of the color-chart, and let us inquire how the latter would look if the lines of division were so arranged that the *apparent difference in the hue of the color* between each two compartments would remain the same upon the whole of the circumference. This end will be reached if we imagine

Fig. 43.



the ideal color-chart, which in reality always remains the same, to be covered by a system of dividing lines such as is represented, for the circumference at least, in Fig. 43.

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The several hues thus obtained are the following: Purple, carmine, vermilion, orange, yellow, yellowish green, green, bluish green, turquoise-blue, ultramarine, bluish violet, purplish violet. To the one hue, green, there are here opposed on the other side three different complementary hues.

This must not, however, be understood to mean that the same green is qualified to complement purplish violet, purple, and carmine, so as to form white with either. For this purpose there would indeed be needed different modifications of the green, of which the first would approach yellowish green, while the third would tend toward bluish green; but the differences among these three hues would hardly be perceptible when compared to the differences which exist between purplish violet and purple, and between purple and carmine.

If we imagine the ideal color-chart, with all its infinite transitions, to be really executed in colors, its appearance will always remain the same, no matter whether we divide it into ten or into twelve compartments. But if we confine ourselves to a finite number of hues, say ten or twelve, as in the case under consideration, and if we fill up each compartment uniformly with the hue allotted to it, the appearance of the chart will vary according to the manner of division chosen. The division into ten compartments is of advantage because it gives pairs of complementary colors which are easily retained by the memory. The division into twelve, on the contrary, that is to say, the division according to hues which differ equally from each other, offers other advantages, so that we shall avail ourselves of the one or of the other as occasion may require.

The advantages of the latter mode of division are to be sought in the fact that it appears to be endowed with an especial importance from an æsthetic point of view. It might not perhaps be improper to speak of "intervals" here, as in music, and the scale of colors just described might be called the "scale of twelve intervals," or perhaps still better

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the "scale of *equal* intervals," as the number "twelve" is of no special importance.

Whenever, therefore, colors are spoken of which are separated from each other by an equal number of steps or intervals of the color-circle of twelve divisions (as on p. 192, *et seq.*), this expression will have to be understood in the sense here explained. We can then also say that the distance between bluish violet and vermilion is the same as that between vermilion and green, that is to say, four intervals of the circle of twelve divisions, although the geometrical distance upon the color-chart differs very considerably in these two cases.

Attention must here be called to still another circumstance.

57. Difference in brightness of complementary colors.

If we group together the complementary pairs of the purest possible colors, we shall find that they possess very unequal degrees of brightness. As a general rule, it is indeed quite difficult to judge of the proportional brightness of the various colors as long as the differences are very slight, and it is frequently impossible to say whether or not two different colors, a blue, for instance, and a brown, or a green and a dark red, are equally bright. But nevertheless there are still other cases in which we can assert with positive certainty that one color is darker or brighter than another.

We shall immediately see, for example, that, when mixing spectral yellow and blue to produce white, the first must be much brighter than the second, and that the violet which is to be the complementary of yellowish green must be much darker than the latter.

In short, we shall observe that we must give to the colors upon the circumference of the color-circle about the same degrees of brightness which they possess in the spectrum, or, more correctly speaking, which they would possess in a spectrum in which equally broad spaces correspond to equal differences in the number of oscillations. In such a spectrum the red would occupy more space than in the prismatic

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spectrum, and would therefore appear somewhat less luminous in proportion, while the violet would be crowded together into a smaller space, and would therefore be somewhat brighter.

It may be said that the various colors are represented in daylight in the relative degrees of brightness which are due to them in such an ideal spectrum. We therefore meet with the colors in the same relative degrees of brightness in colored bodies, since all such bodies select certain rays from the light offered to them (see § 21), and since it appears improbable that bodies in general should have a preference for any one color rather than for another. We have consequently accustomed ourselves to speak simply of light and of dark colors, and to attribute to each color, as peculiar to it, that degree of brightness which we observe as its mean. Thus we call yellow a light color (although it would be better to speak of it as a *bright* color), while we designate blue and violet as dark colors. (See p. 100.)[11]

Calling these degrees of brightness their *natural* brightness, we may say that pure colors of the proper hue will complement each other so as to produce white if mixed together in their natural proportional degrees of brightness.

If we examine the distribution of brightness upon the color-chart we shall find violet and yellow, or rather a somewhat greenish yellow (yellow ultramarine), to be the two extremes; all possible gradations are represented between these two. The boundary between the light and the dark colors is in the direction of orange and turquoise-blue.

58. Each color has an infinite number of complementaries. The explanation just given might easily lead the reader to suppose that each color has but one complementary. But this is true only when a certain definite degree of purity is required. If this demand is waived, numberless complementaries will be found to exist for each color, which complementaries must indeed be all of the same hue, but which will nevertheless admit of a great variety, as regards brightness and purity.

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This proposition, which is of great importance for æsthetics, will be easily understood after the following points have been considered:—

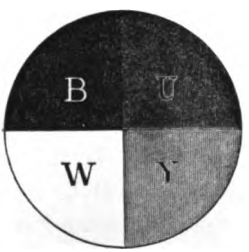
According to the law of mixtures we can conceive of the colors to be mixed as weights which are proportional to the degree of brightness of the colors. The result of the mixture will then be found at the point of equilibrium of the weights. If the mixture is to be white, that is to say, if the two colors are to be complementaries, they must, under all circumstances, be situated upon a straight line passing through the central point of the color-chart. For any one given color on the color-chart, any color situated upon the same straight line at the other side of the white may serve as the complementary, if only we adjust the weights correctly.

A pure color may have a pale one for its complementary, if only the brightness of the latter is sufficiently great; a pale color, that is to say, one mixed with white, can be neutralized by a pure color, if only the intensity of the latter has been sufficiently reduced.

But in such a case it may happen that the two colors which complement each other exhibit an extraordinary difference in their appearance, the one showing almost no color at all, while the other appears to be very full.

The observation just made can be shown more clearly by an experiment.

Fig. 44.



Given a blue and a yellow which, when applied to equal areas upon the rotating disk, will produce white. In that case we shall still obtain white (gray) if, instead of painting one half blue and the other yellow, we paint only one quarter blue (*B*, see Fig. 44), another quarter yellow (*Y*), and the remaining part of the disk white or black, or both in any

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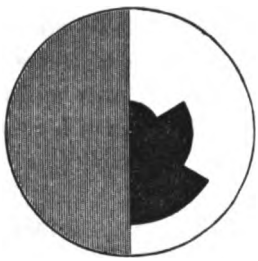
arbitrary proportion. We will assume that the area still at our disposal has been painted, one half black (*B*), the other half white (*W*).

It is, however, self-evident that the result must be exactly the same if we paint the left half of the disk with a mixture of one part of black and one part of blue, and the right half with a mixture of one part of yellow and one part of white. The result of these mixtures we can easily find by means of the color-top, and we shall then observe with astonishment that the mixture of blue and black produces a blue which, although dark, is still very full, while by the mixture of yellow and white we obtain a white with only a faint tinge of yellow. But these colors are nevertheless complementary, of which fact we can again very easily convince ourselves by an experiment.

Mineral-blue, for instance, laid on white paper in a layer of medium thickness, and deep *jaune-brillant*, in a very thin layer, are complementary, that is to say, if the two halves of the rotating disk are painted with these colors they will produce white. Yet, to judge by the direct impression made by them upon our senses, these two colors appear to be so far from equivalent that the fact of their neutralizing each other appears to be almost an impossibility.

If we divide the rotating disk into two parts, and then paint one half with any one color, and the other half either with white or with black or with neutral gray, all the colors produced by rotation will be of the same value in a mixture. One and the same color is capable of producing white with all of them, and yet they appear to be exceedingly different from each other, as may best be seen by arranging the disk in the manner shown by Fig. 45, the left half being

Fig. 45.



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colored and the other half supplying white, two grays, and pure black. While the mixture with white almost absorbs the color, the black exercises but a slight influence.

Our eye, therefore, has no standard whatever by which to measure the value of a color in a mixture, and this circumstance is a most striking argument against an æsthetic theory which is very frequently met with.

59. Field's chromatic equivalents.

It is often maintained that the individual colors in a colored ornament should be so chosen, both as regards hues and the areas assigned to them, that the resulting mixture, as well as the total impression produced when such ornaments are looked at from a considerable distance, should be a neutral gray.

Starting from this idea, the attempt has been made to fix the proportional size of the areas, which would have to be assigned to the various colors usually employed in the arts, for the purpose of arriving at the result indicated. This idea was especially elaborated by FIELD, an Englishman, who gave the name of "chromatic equivalents" to the numbers of the proportions obtained, a designation which has since been very generally adopted.

In reality, however, these "chromatic equivalents" have no value whatever. For, to begin with, the methods which Field employed for determining his equivalents were totally wrong, as, in his experiments on mixtures, he made use of absorbent media, that is to say, of colored fluids, which he placed one behind the other, and from which, as we have learned at the commencement of this chapter, the results of the mixture of colors can never be obtained; and, secondly, the experiments and observations just made have shown us that the basis of his theory is entirely untenable.

For colors may be complementary to each other, and yet the impression made by them may be of such unequal value, æsthetically, that they can never be equally employed in one and the same ornament. This circumstance could only escape

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Field's attention because the chromatic equivalents, as determined by him, are entirely incorrect, and because a pattern composed according to his directions will not in reality produce neutral gray as a mixture. And indeed one glance of an unprejudiced eye will be sufficient to convince any one that the best paintings, as well as the best ornaments and woven fabrics, do not in the least make the impression of neutral gray, when seen at a distance, but that on the contrary they show a very decided, characteristic color, or dominating hue.

60. Colors and sounds. Having thus gradually passed on from physics to æsthetics, we must now examine still another group of æsthetic theories which rest upon a different basis.

The attempt has been made to render the wave-theory of light available for æsthetics, and for this purpose the analogies between musical sounds and colors were chosen as a starting-point.

The first doubt as to the correctness of this theory arises from the fact that the limits within which colors and sounds may be perceived differ considerably for both.

While the deepest tone still perceptible to our ear executes about 30 vibrations in a second, the highest executes 24,000.[12] Increasing the number of vibrations still further, we either receive only a sensation of pain in the ear, or we hear nothing at all. The sounds used in music range from 32 to 4,000 vibrations, comprising about seven octaves.

In the case of color-sensations, however, these conditions are entirely different. While the red at the extreme end of the visible spectrum executes 407 trillions of vibrations, the extreme violet executes 793 trillions, so that the sum total of our sensations of color does not correspond even to a single octave; for in that case the extreme violet would have to execute 814 trillions of vibrations. It is indeed still possible, as before observed, to perceive light of such a number of vibrations, and even of a still higher number; but the color-

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sensation received, instead of being clear and unequivocal, is weak and indefinable.

It will be seen, therefore, that very considerable differences exist between the limits within which we are susceptible to sounds and to colors. But the same is true to a much higher degree of the manner in which sounds and colors co-operate with each other.

If several notes are sounded simultaneously, we do not hear a sound of medium pitch, but we hear a consonance, a chord, of greater or less euphony, which it will not be easy to mistake for a simple sound. According to the degree of practice attained by the hearer, it will even be possible to distinguish the various sounds composing the chord. The surprising degree of skill to which the human ear can attain in analyzing masses of sound may be observed in well-schooled musicians, who are able to follow each instrument and each voice in a full orchestra or chorus. A noise, instead of a musical sound, is only heard when the vibrations of the air take place without any regularity, or when a great many sounds burst upon the ear simultaneously, and wholly without regard to law.

In the case of sensations of color this is again quite different.

Whenever several colors act simultaneously upon the same spot on the retina, we see a mixed color, that is to say, again a simple color[13] (the analogue of the musical sound), only somewhat weakened by the admixture of more or less white (the analogue of noise). No eye is capable of recognizing the elements which compose such a mixed color. The artist, indeed, may *know* that a given mixed color can only be produced by such and such pigments, but he can no longer *see* the component elements in the mixture itself.

We may sometimes be led to believe, as, for instance, in the case of reflection from polished plates of glass, that we see two colors in the same place, or that we see one color

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through another, as if through a veil; but it will always be found that our judgment is guided to a knowledge of the component elements by accompanying secondary circumstances, and that the eye, as such, cannot give us this knowledge.

If we remove all conditions which can influence the judgment, we shall at the same time destroy all possibility of resolving the mixture into its component parts. The eye of even the most practised artist is utterly incapable of deciding whether a gray upon the rotating disk is mixed from white and black, from yellow and blue, or from purple and green.

The law of mixtures expresses this fact. It teaches us that, according to the method above illustrated by a specific example, each mixed color can be produced from simple colors in an infinite variety of ways, and it therefore contains an essential difference between sensations of sound and of color.

If there existed a complete analogy between the two classes of sensations, every mass of sound would resolve itself into one tone, or into a confused noise, and all polyphonous music would be made impossible.

But there is still another difference, of a very radical kind. A tone will be perceived as such even when only a few of the vibrations by which it is formed are executed, although it is of advantage to euphony even in this case, if the number of vibrations reaching the ear is not too small. The proof of the statement just made is found in the well-known fact that rapid passages in the lower regions of sound do not make a pleasant impression, but are apt to become indistinct and confused, while it is a favorite custom to give such passages to high voices. When deep sounds succeed each other quickly, only a few vibrations, perhaps not more than ten or twenty, are allotted to each sound, while in the higher regions, even with very quick time, the vibrations which enter the ear during the sounding of each note are counted by hundreds.

With colors the case is quite different. The disk of the

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color-top appears of a perfectly even color, when it rotates thirty times in one second under ordinary conditions of light, twenty times in a low light, fifty times in very strong light. We can therefore no longer recognize the succession of colors when the latter succeed each other in intervals of less than $\frac{1}{40}$, or, according to circumstances, $\frac{1}{100}$ of a second. Adopting the latter number as a basis, and assuming the disk to be illuminated by red light, we shall find that even during this short period of time five trillions of vibrations enter the eye. If these are again succeeded by others of a different period of vibration, and so on in continuous alternation, the two sensations of color will still be perceived as a whole, that is to say, as a mixed color, and not successively as two colors.

The impression of a succession of colors can only be produced when the number of vibrations entering the eye from each color exceeds five trillions, and even then it will be quite imperfect and more of the nature of a glitter. When two sensations of color alternate rapidly with each other, as in the case of the rotating color-top, the disk of which is painted with two different colors upon its two halves, the process is analogous to the trill, or to the tremolo, in music, in which two sounds likewise alternate with each other in equal intervals. If such a trill were to be executed so as to correspond exactly to the operation performed by the alternating colors upon the rotating disk, or, in other words, so that each sound would execute a number of vibrations equal to the number of vibrations of light which must enter the eye to produce the effect of alternating colors, the sounds would have to succeed each other in periods measuring at least years.

Generally speaking, the number of vibrations of light which are needed to enable us to perceive a sensation of color appears to be very considerable. Experiments lately made have shown that in a faint light the impression must continue for at least $\frac{1}{500}$ to $\frac{1}{200}$ of a second, if it is to give rise to a

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sensation of color, showing that for this purpose the eye must still be acted upon by trillions of vibrations of the same kind. In a strong light this number is indeed considerably reduced, since the illumination by a single powerful electric spark is sufficient to render colors perceptible. But even this shortest of all illuminations which can be produced lasts several hundred thousandth parts of a second, according to the experiments of FEDDERSEN, so that the vibrations of light emitted by a colored object during the period of its duration must still be counted by millions.

This detailed comparison between colors and musical sounds has only been entered upon because the attempts to place both departments upon the same æsthetic basis are continually springing up again.

The present discussion of the subject has shown that such analogies do indeed exist, but only to a very moderate extent, and that the connecting link between the two departments is of a very doubtful nature, so that many of the attempts alluded to hardly deserve to be called anything else than clever fancies.

Considerable differences between sensations of color and of sound can also be seen from still another point of view. Taking the numbers of vibration as a basis, we can of course conceive the colors to be arranged in scales, analogous to the musical scales, in which case we shall have at our command an interval of about an octave. But while in the musical scale the intervals are involuntarily indicated by our musical feeling, we are left entirely at a loss by our judgment in the formation of such color-scales. Take, for instance, an interval of a fifth, that is to say, two sounds, the numbers of vibration of which are as two to three. A naturally good ear, even with a very deficient musical education, will immediately feel when these proportions are reached, while it perceives variations towards either side as discords, and feels that the two notes are "out of tune."

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With the eye it is different. The numbers of vibration of the red of the Fraunhofer line *C*, and those of the ultramarine-blue a little on the other side of *G*, are likewise as two to three, that is to say, they correspond to an interval of a fifth, but it is absolutely impossible, even for the eye of the best colorist, to determine the exact point at which just this proportion is reached. Variations of tolerable importance towards either side are admissible, and it can neither be said that the combination deteriorates in consequence of these variations, nor that it improves again after other intervals have been reached, say, for instance, the fourth (which would find its place in the turquoise-blue) or the third (green).

There are colors, indeed, which do not harmonize with each other, but the reasons for this disharmony, as will subsequently be shown, are quite different from those which prevail in the case of musical intervals.

The observations above made are still more strikingly illustrated by sounds or colors, the vibrations of which are as one to two. This proportion corresponds to the octave. But while in music the octave differs so characteristically from all other intervals that an unpractised ear may easily confound the fundamental tone and the octave, the difference between the colors at the two ends of the spectrum, in spite of a certain affinity between the two, and even when the ultra-violet is made sufficiently visible (by shading off) to produce the octave of the extreme red, is still of extraordinary magnitude.

But the part which the interval enacts in music, æsthetically speaking, is, under all circumstances, quite different from that which it plays in painting and the kindred arts.

While music can only progress from note to note by fixed degrees, and while gradual transitions (notes drawn into each other) produce the impression of howling, such transitions are of the greatest importance in painting.

The smallest interval which music admits of is a half-note,

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and even this interval must only be employed sparingly, as shown by the chromatic scale, the value of which may be an object of discussion, unless when used in "sound-painting" to imitate the howling of the storm, etc.

Those arts, on the contrary, which depend upon color for the production of their creations, must of necessity employ all conceivable transitions, as otherwise they will find their place in a lower category, such as mosaic, etc.

61. The physiological fundamental color-sensations of the retina. The law of mixtures, together with the system of colors based upon it, having now been considered from the most varied points of view, it may not be out of place to devote a few words to the attempts which have been made to explain this curious law.

Before, however, proceeding with our discussion we must call attention to a fact which may indeed be inferred from the color-chart, and which is so closely connected with the question presently to be considered that it appeared best to defer its investigation until now.

It has been shown above that, by the mixture of any three colors, arbitrarily chosen, all those colors can be produced which are situated upon the color-chart within a triangle, the points of termination of which are formed by the colors in question. Accordingly, by mixing three colors we can produce mixtures which correspond to all conceivable hues, as long as the triangle contains the place which is occupied by the white.

This fact, which also asserts itself, although with some modifications, in the case of mixtures of pigments, induced the physicists at a very early period, even before the time of NEWTON, to assume three fundamental colors.

Originally a physical significance was attributed to these fundamental colors; that is to say, the white light of the sun was assumed to be objectively resolvable into three such fundamental colors, an assumption which has, however, been completely disproved by the experiments described in the first chapter.

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But the idea of fundamental colors was, nevertheless, again taken up at a later period, although in a somewhat different shape, at first by the English physicist YOUNG, who rendered invaluable service to theoretical optics, and after him by HELMHOLTZ.

These two investigators ascribe to the fundamental colors, not a physical, but a physiological significance. They assume that the eye is accessible to three fundamental sensations, which we may perhaps conceive of as being made perceptible to us by means of three different kinds of nerves or of nerve-terminations. It is supposed that all the various color-sensations experienced by us owe their origin to the co-operation of these three fundamental sensations.

The question is, therefore: To which colors do these three fundamental sensations correspond?

But this is a question which cannot be decided offhand. Each triad of colors so situated upon the color-chart that the triangle, the corners of which contain the three colors composing the triad, encloses the place occupied by white, would be suited to the purpose, since, by the mixture of three such colors, we can produce colors of all hues.

Red, yellow, and blue were generally looked upon in former times as the fundamental colors, the results obtained by the mixture of pigments having been accepted as a basis.

Later investigations lead to the conclusion that green must be substituted for yellow, and a variety of reasons might be cited, all of which speak unanimously in favor of assuming *red*, *green*, and a *blue* which borders closely upon violet, to be the fundamental colors.

The conclusion that the sensations of red, of green, and of a deep blue are of a simpler nature than those of any other color, is especially supported by certain pathological phenomena, which are known by the name of defective color-vision.

62. Color-blindness. It is a well-known fact that some persons find it difficult to tell one color from another, and

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that consequently they make mistakes which appear perfectly incomprehensible to a person of normal vision. Taking red for green, for instance, is one of the mistakes most frequently made. There are persons to whom the color of a ripe strawberry does not differ from that of the surrounding leaves. Thus it actually happened that a gentleman bought scarlet cloth for a green hunting-jacket which he wished to have made.

Such mistakes are frequently very unpleasant for the persons concerned; and upon railroads or vessels where it is necessary to observe colored signals they may become absolutely dangerous.

The author recollects having read of a collision of two trains, which was brought about simply by the fact that one of the employees mistook a green signal-lamp for a red one. Better attention than heretofore ought to be paid to this point in the professions in question, and if possible such signals ought not to be based upon color alone, but the main stress ought to be laid upon form and arrangement.

But the errors to which such persons are exposed are not confined only to mistaking red for green. Similar errors are sometimes made by them in the case of rose-color and blue, as well as in some other cases of a less striking character.

Furthermore, there are also cases of defective color-vision in which other colors are involved, as for instance blue and yellow. And finally we can deprive ourselves of the feeling for color by artificial means.

Such a means is found in the santonine, the most important element of worm-seed. A person partaking of this medicament is brought to a peculiar condition of intoxication, which is followed by vertigo and headache. In this condition all objects are seen in only two hues, yellow and violet. Violent injury of the head, or overstraining of the eyes, can also induce the loss of the color-sense.

In some countries defective color-vision is more frequent

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than in others, and to a degree which appears almost incredible. In England, for instance, one person out of eighteen is said to be afflicted with it.

Color-blindness, as this malady is appropriately called, is hereditary, and is often coupled with a defective musical ear. With women it is of less frequent occurrence than with men, so that it may not be incorrect to ascribe a more perfectly developed color-sense to the female sex in general.

May not the interest in beautiful dresses, which is shown by girls at a very early age, be instrumental in the development of this sense?

Upon closer investigation all the mistakes just alluded to, which at first sight appear to be so curious and independent of all rules, may be reduced to three groups.

Color-blind persons of the first group, for instance, who are principally liable to confound red and green, when examining a spectrum, will see it shortened at its red end. The place in which the red is visible to a normal eye is perfectly dark to a color-blind person of this class. Red light does not affect his eye; he is blind, as far as these rays are concerned. In such a case the malady is therefore called red-blindness. When intoxicated by santonine the violet end of the spectrum is wanting, on the contrary, and this condition may therefore be designated as violet-blindness. The violet shadows seen under the influence of santonine are therefore simply the consequence of contrast, that is to say, a deception of the judgment.

The instances cited may suffice to show that these phenomena can easily be explained by the theory of the three fundamental sensations. It is only necessary to assume that color-blind persons are devoid of one or the other of these fundamental sensations. If we suppose that these sensations are brought to our perception by nerve-fibres especially assigned to each, it is presumable that in the case of a red-blind person the fibres corresponding to the sensation of red are

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either paralyzed, or that they are perhaps even wanting entirely, while in the case of a violet-blind person the same would have to be true of the nerves set apart for the violet sensation.

It is not difficult to arrive at an idea of the condition of a color-blind person, at least approximatively. We need only to hold a piece of colored glass before the eye, and we shall immediately be liable to make the most curious mistakes.

Lamplight acts similarly, and in such a light our condition is nearly analogous to that of a violet-blind person. If a painting were executed by lamplight it would look strange and faulty by daylight, and its incorrectness would increase with the number of cold colors intended to be employed in the picture.

Unfortunately there is no colored glass by means of which the condition of color-blindness can be exactly imitated, but we can place ourselves in the condition of of a red-blind person, by pouring a solution of sulphate of copper into a glass vessel with flat, parallel sides, and then looking through the liquid. Examining a sample-chart of colors, or a spectrum, under such circumstances, we shall be exposed to precisely the same mistakes as a red-blind person.

On the other hand, color-blind persons, by using colored glasses, can tell the difference between colors which ordinarily they would confound with each other, and a few pieces of glass of suitable color, mounted like eye-glasses, might therefore prove to be of great service to such persons. Color-blind people, whose profession requires that they should be able to tell the difference between colored signals, patterns, etc., or to study or design technical drawings, such as plans, charts, etc., might by these means procure very essential relief at almost no cost.

The lower degrees of this malady are undoubtedly very frequent, and can hardly be discovered in the ordinary course of life. The want of a finer feeling for color will only show

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itself when the profession chosen by such persons brings them into contact with colors. It will then assert itself as bad taste, or, in the case of an artist, by the bad color in his pictures.

The fact that there have been painters who never succeeded in mastering color, although their feeling for form was highly developed, their talent for composition eminent, and who were on the whole gifted with extraordinary artistic and creative powers, points unmistakably to the conclusion that in this instance they were contending against a physical defect, the victory over which was impossible to them. It would be an easy matter to recall some great names among the artists of the earlier Munich school to whom the observations just made might be applied. It is a curious circumstance, however, that these artists were led, of their own volition, to avoid the one manner which makes the largest demands upon color, that is to say, oil-painting, and to employ, with evident preference, the wet lime (the fresco manner), or water-colors, slightly treated, as the medium in which to embody the offspring of their genius.

Whenever depth and grandeur of thought, rigorously expressed, speak to the observer, or when finely conceived forms of surpassing beauty unfold before the enchanted eye the treasures of a rich and profound mind, as in the case of the masters who are present to my mind as I write these words, we may well be inclined to overlook even the absence of the harmony of color.

But it is a pitiable spectacle to see artists of less talent, whose eyes have been dazzled by the grandeur of these heroes, endeavoring to imitate even their defects, and thus to see arise whole schools in which the comprehension of color is completely wanting.

63. Modified color-chart. The conclusions which were arrived at from the observation of color-blind persons formed for a long time the most important points of support for the theory of the three fundamental sensations.

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Later investigations have considerably increased the number of reasons which speak in favor of this assumption.

The weightiest of these reasons is the form of the color-chart. The circular form, which NEWTON originated, and which we have continually made use of for the sake of its simplicity, can only be looked upon as an approximation. The color-circle is in fact only a piece of the true color-chart, which latter approaches the form of a triangle, in the corners of which the colors red, green, and bluish violet find their place.

If the colors in the color-circle are to fulfil all the requirements of the law of mixtures, and if we have introduced into this circle the fullest possible yellow and the fullest possible bluish green, it will be impossible to find a place in it for perfectly full red, green, and ultramarine (which color we shall have to choose if we operate with pigments, as the latter offer no good representative of violet). We shall therefore have to assign places outside of the circle to the three colors last named, thus giving to the whole a form which approximates that of a triangle.

But the theory of the three fundamental sensations likewise demands that the color-chart should be a triangle, and according to the same theory the corners of this triangle must be occupied by those very colors which are also assigned to the same places by the experiments on the mixture of colors.

The color-circle represented in Fig. 46 has been constructed with the aid of the color-triangle, that is to say, it is to be looked upon as a section cut from the triangle, and in this special case as an enlargement of the small circle represented within the color-triangle. The circumference is marked with lines, which denote the number of vibrations, so that, in progressing from line to line, we meet at each new line with a color executing 10 trillions more of vibrations in a second than that having its place at the previous line. The number 50 denotes that light of this special color executes 500 tril-

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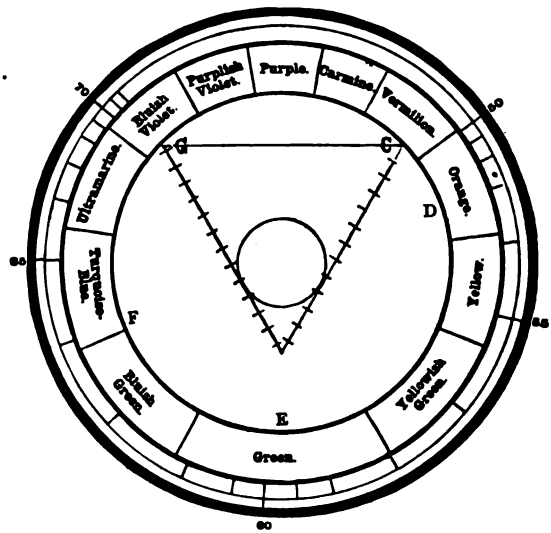
lions of vibrations in one second, and so on. To be able to compute these numbers it is necessary to know the velocity

Fig. 46.



with which light is propagated through space, and the determination of this velocity is again dependent upon an exact knowledge of the distance between the earth and the sun. Every new and more reliable measurement of this distance is therefore accompanied by small corrections in the numbers alluded to, and this explains why the number of vibrations for certain Fraunhofer lines is frequently given differently in different works. These small variations are, however, without importance for our immediate purpose. (See p. 14.)

The distribution of these lines represents the law of mixtures in a strictly mathematical form, and is of itself sufficient to point to the peculiar position of the three colors red, green, and bluish violet.

From this color-circle we can now also judge of the distri-

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bution of the colors in the spectrum, as the number of vibrations due to its various parts is well known. But in this connection we must not forget what has before been said regarding the uncertainty of the limits of the several spectral colors (see §§ 10 and 11), and the fact that the sodium line *D* is here represented as having its place in *orange* (see Fig. 46), while otherwise it is usually designated as *yellow*, need not cause any astonishment. The area occupied in the spectrum by orange and by yellow is indeed quite limited, while at the same time the transitions are so gradual, and the influence of different degrees of brightness upon the hue is so potent, that it is impossible to assign sharply defined boundaries to the various colors. At a lower degree of brightness the sodium line appears orange, at a higher degree it appears yellow. But in spite of the uncertainty prevailing in this particular, the accompanying figure will nevertheless serve to show very plainly that the colors red, green, and violet (including part of the ultramarine) occupy proportionately larger spaces in the spectrum than the hues which are situated between them.

The circumstance that, in progressing according to hues which differ equally from each other, the same number (that is to say, three) of intermediate hues must always be intercalated between each two of these hues likewise accords exceedingly well with the views of Young and of Helmholtz.

For if we suppose that all the colors situated between red and green are produced by the co-operation of the fundamental sensations of these two colors, or, more generally speaking, that all the colors situated between the hues corresponding to any two of the fundamental sensations are brought to our perception by means of the simultaneous action of these two fundamental sensations, nothing appears to be more natural than that in the transition from one fundamental color to the other there should be also an equal number of intermediate stages.

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The theory of fundamental sensations furthermore demands that the specific impression of color should be much more decided when only one of these fundamental sensations is called into action than when two or even all three are simultaneously excited. In other words, the fundamental colors must excel the others in fulness.

And this is indeed the case.

Vermilion, Paris-green, and ultramarine are the fullest of all known pigments, while yellowish green and bluish green, or turquoise-blue, can never compete with these colors as to fulness.

If we endeavor to produce such hues of the greatest possible fulness, we shall forthwith observe that the lighter shades appear pale, while the darker ones are without effect on account of their low degree of luminosity.

According to this theory yellow is not a fundamental color, and it therefore follows that it must possess a less degree of fulness than red, green, or ultramarine-blue. This statement may at first appear to be doubtful. Nevertheless, even the most intense yellow will always appear somewhat whitish, provided we really confine ourselves to pure yellow, and do not select a so-called golden yellow, which already approaches orange.

The same circumstance will assert itself still more strikingly when we observe that one among woven fabrics which, above all others, brings out color, that is to say, velvet. Yellow is not a color for velvet, quite as little as yellowish green or turquoise-blue, while red, green, and violet produce an excellent effect in velvet.

If it be admissible to look upon the value which a hue possesses as a color for velvet, as upon a standard by which to measure its fulness, we can make use of this fact for the purpose of adducing still another proof of the correctness of the theory just laid down.

A closer inspection of the color-triangle will show that in

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the case of mixtures produced by the co-operation of the fundamental sensations red and violet, the loss in fulness which takes place cannot be as considerable as in the case of the mixed sensations excited by the fundamental sensation of green in combination with either of the other two sensations. And all the hues of purple will in reality be found to furnish splendid colors for velvet, provided that they are employed in the greatest possible purity, or, in other words, as free as possible from white.

The vegetable world offers very good representatives of these hues, of a high degree of fulness, in the petals of a number of flowers. Similar representatives are also found in various combinations of aniline.

In the discussion of these problems we must not, however, lose sight of the fact that great difficulties are experienced in endeavoring to arrive at a definite solution of the question as to the places in the spectrum which correspond perfectly to the fundamental sensations, and that physicists have so far only succeeded in giving an approximate solution. This explains why some name blue as the third fundamental sensation, while others name violet. In reality the corresponding place in the spectrum appears to be situated very near the line *G*, that is to say, near the boundary line between blue and violet. The uncertainty in the designation of the third fundamental sensation, which is caused by the circumstances just alluded to, is still further increased by the fact that the most refrangible rays of the spectrum, that is to say, the blue and the violet, are just those in which changes in the degree of brightness produce the greatest changes of hue. Of this we can easily convince ourselves, by folding a piece of paper or of cloth of a deep ultramarine-blue so that it will show places which are brightly illuminated and others which are in deep shadow. In this case the shadows appear violet, while the lights are decidedly blue. Certain it is, however, that, whenever pigments are concerned, that is to say, in the

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case which here interests us most, deep ultramarine-blue will always have to be looked upon as the representative of the third fundamental sensation, or, in other words, of that sensation which corresponds to the most refrangible end of the spectrum.

64. Yellow not a fundamental color.

The most important result for æsthetics which the investigations into the physiological fundamental colors have yielded is undoubtedly to be found in the fact that yellow has been struck from the list of fundamental colors, and that green has been substituted for it.

In the closing chapter, which treats of the combination of colors, we shall see that this assumption is fully justified, even from the artistic point of view.

Yellow was formerly included among the fundamental colors from purely technical motives. This was simply owing to the fact that green can be produced by mixing yellow and blue pigments, while by the mixture of green and red only a very dark yellow, that is to say, a brown, can be obtained.

This purely technical consideration finally succeeded in prejudicing even the judgment, so that writers upon art imagined they saw their so-called "primary colors," as the basis of the chromatic composition, in the works of art of the best periods, while a somewhat more careful inspection will readily show that the choice of colors in these works is influenced by considerations of an entirely different nature.

It is true, for example, that in Moresque art, to which the first place may perhaps be assigned in respect to ornament, red, blue, and yellow, that is to say, gold, are the colors principally met with.

But in these works of art yellow plays a part in the composition which is quite different from that assigned to the other colors, and furthermore, instead of yellow pigments, which are seen but seldom, gold is almost always employed.

In Moresque art, as well as in all other styles which have

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reached a higher development, yellow always occupies an exceptional position, and is never applied like red and blue.

While red, blue, and green are the colors given to surfaces, yellow is used for linear ornament, for projecting mouldings, nail-heads, etc., occupying a position closely allied to that of gold or silver, or of its substitute, white. In short, yellow enacts the same part in ornament which is assigned to it in heraldry, in which latter, as is well known, it likewise does not count for a color.

Yellow occupies an exceptional position even in the spectrum, being the lightest color found in it, and this position is made still more prominent by the fact that it is at the same time the color of gold, the most precious material and the most costly adornment at the command of the decorative artist.

With green it is different. Although it plays a subordinate part in Moresque ornamentation, and probably also in the early period of Greek polychromic art, the Persians and Indians, and perhaps also the Turks, have a fancy for it, and employ it precisely like red and blue, while yellow invariably retains its peculiar position as a decorative means of a higher order.

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FOURTH CHAPTER.

THE THEORY OF CONTRAST.

65. Successive contrast. In all the phenomena so far investigated the color observed was wholly dependent upon the nature of the bodies or of the surfaces under consideration and of the lights by which they were illuminated. We will now turn to a class of phenomena in which colors are called forth, or are at least influenced, by other impressions of color, either preceding the former in time, or else asserting themselves simultaneously. Colors which originate in this manner, that is to say, by *contrast*, are called *subjective colors*, and the phenomena of contrast are divided into two groups, namely, those of *successive contrast* and those of *simultaneous contrast*.

The changes which are produced in colors by contrast have reference to brightness as well as to fulness and to hue. They play so important a part in painting, and in all the chromatic arts, that CHEVREUL simply entitled his great work on the theory and the harmony of color the "Theory of Simultaneous Contrast." While the artist who works with colors may abandon himself with tolerable success to his feeling and to routine in all other matters relating to the treatment of color, it is absolutely necessary for him to know the laws of the phenomena of contrast. These he must be familiar with if he wishes to avoid groping about in complete darkness, and if he desires to reach his aim without the necessity

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of endless corrections, which latter may after all lead him to only an imperfect result.

Before proceeding further we will acquaint ourselves with the simplest experiments bearing upon this subject.

Lay a small white disk, say a white wafer, upon a black ground; look steadily at it for some time, perhaps ten to fifteen seconds, and then turn your eye to another surface which is uniformly illuminated, best of all a sheet of gray paper. You will see upon this gray surface a *dark* image of the form and the size of the *white* wafer.

Instead of the white wafer use a colored one, and the image upon the gray surface will also appear colored, but its hue will be that which complements the color of the wafer.

If a red wafer has been used, the after-image — for this is the name given to these images which remain behind in the eye and then gradually disappear — will be bluish green; in the case of a yellow wafer it will be blue, etc.

If, after having fixed our eye upon an object for a sufficient length of time, we look upon a surface of the same color as the object, the after-image will appear faint and whitish; if the surface looked upon is of the complementary color to that of the object, the after-image will appear deeper and more brilliant than the rest of the surface.

To prove this fix your eye upon a bluish green wafer on a gray ground, and then turn suddenly to a bright red surface. The after-image of the wafer will appear in a red of still greater intensity. Even to the fullest color that can be produced a still fuller one can be opposed in this manner, and indeed even to the spectral colors a still greater degree of fulness may be imparted by means of such after-images.

In passing, it may be well to draw attention to some peculiarities which attach to these after-images. First of all, it will be observed that they appear to move with the eye, and at the same time to change their size. The more distant the

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surface upon which we cast the eye, the larger will the after-image appear, — a very interesting experiment, showing the influence exercised by the judgment upon sensual perceptions.

If we look upon a colored surface after having fixed our eye upon an object for a sufficient length of time, the color of the after-image will mix with that of the surface, and the image will appear in the mixed color. If the object was green, the after-image will appear violet if seen upon a blue surface; orange-yellow if seen upon a yellow surface; faintly green, with a tendency towards gray, if seen upon a green surface.

The rule, therefore, is exceedingly simple: *Any colored object will leave an after-image of the complementary color, provided that our eyes have been fixed upon the object for a sufficient length of time. The color of the after-image mixes with the color of the body or surface upon which the eye is afterwards directed, or, to use a very apt term, upon which the after-image is projected.*

Such after-images are called *negative*, because they hold the same position to the object producing them which the photographic negative holds to the original, that is to say, because a dark image corresponds to a light original, and *vice versa*.

There is still another class of after-images, which appear of the same color as the object, and which are therefore called *positive*. Such images may be obtained by looking at a very bright object, a burning lamp, for instance, for a very short period of time, say not longer than for the third of a second, and then suddenly closing the eyes, or, still better, covering them with the hands or with some dark object, while at the same time the head and body are held as still as possible. In this case the object will be seen for some time in its natural color; the original image remains behind in the eye for some time. This phenomenon owes its origin to the persistence of visual impressions, of which we have previously treated in detail. These positive after-images are without special importance to the subject in which we are at present

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most interested, and it will therefore be sufficient here to have mentioned the fact of their existence.

The appearance of the negative after-images is explained in the following simple manner: If the eye is exposed to the same impression for any length of time, it gradually grows tired and becomes less sensitive to impressions of the same kind. Very bright colors and impressions of light render us insensible to others, and take away from us the faculty of perceiving small differences.

If only a certain part of the retina has been exposed to such excitation, it will become less sensitive to light than the parts which surround it. That part which has just been acted upon by the image of a very bright object will therefore be less sensitive to subsequent excitation than the neighboring parts, from which it follows that the after-image of a bright object must appear dark upon a light ground. The reverse is true when the object is darker than the ground. In that case the corresponding part of the retina is protected, and is therefore all the more ready to receive the impression of light to which it is afterwards exposed.

The appearance of colored after-images may be explained in a very similar manner. Let us suppose, for instance, that a certain part of the eye has been exposed to a continued impression of red light. It will of course become specially insensible to such red light, and will therefore respond much more readily to the other colors contained in white light, when exposed to the total impression produced by the latter. But these other colors taken together will produce the sensation of green. Upon the basis of the three fundamental sensations the meaning of this observation may be interpreted as follows: In the case just mentioned those organs have principally been fatigued which are sensitive to red, while those which are sensitive to green and to blue are open to new impressions with undiminished vigor.

Similar phenomena can be observed in all departments of

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sensual perception. Thus, after something sweet has been partaken of, other eatables or drinkables are apt to taste sour, and a wine which has a mild and sweet flavor when taken at dinner with roast-beef, may appear quite sour when taken with, or immediately after, a piece of sweet cake.

Successive contrasts are principally observed, as before explained, when the eye is excited by very bright and full colors, and may be looked upon as the result of fatigue. In the fine arts such violent means are generally avoided, and consequently the successive contrast plays but a subordinate part in painting and the kindred arts. In this place it was only alluded to first in order because contrasts are shown in the simplest and most striking manner by after-images, so that the theory of successive contrast is well fitted to serve as an introduction to the whole department.

66. Importance of simultaneous contrast.

With simultaneous contrast it is different. The changes which colors undergo when placed in juxtaposition are among the most important means of pictorial representation in the hands of the artist, and for the purpose of reaching certain definite effects a detailed knowledge of these changes is quite indispensable, especially in those branches of the arts which are compelled to employ colors prepared beforehand, and not admitting of subsequent changes, such as decorative painting, calico-printing, the manufacture of paper-hangings, etc.

Here it is again the contrast between "light" and "dark," which, being the simplest case, is the first to claim our attention.

67. Simultaneous contrast between "light" and "dark."

If we place a given hue, a medium gray, for instance, upon two different grounds, one of them lighter, the other darker, than the gray itself, the latter will assume a different appearance in each of these two cases; that is to say, in the first case it will look darker, in the second lighter. This experiment may be very conveniently made with crayon papers of different shades. If we cut two

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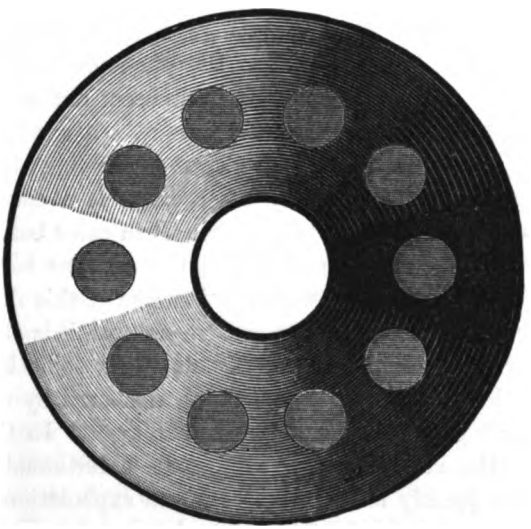
pieces of moderate size from a sheet of such paper, and then lay one of them upon a lighter, the other upon a darker sheet, it will appear almost incredible that both pieces were cut from one and the same sheet, and the fact that they are really of one color can only be realized by placing them side by side.

The same phenomenon can be observed very plainly in Fig. 47. Ten small disks, all shaded exactly alike, are here

Fig. 47.



placed upon a larger disk, the sectors of which differ in shading. The fact that all the small disks are in reality perfectly alike can easily be ascertained by covering the figure with a piece of untransparent paper into which two small holes have been cut, so that two of the disks can be seen through them. But, nevertheless, one half of these small disks appears to be considerably lighter than the other half.

Another remarkable fact to be observed is this, that the disk, the true brightness of which exceeds that of the ground only by a very little, looks almost as bright as that upon the

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perfectly black sector, while in the same manner a disk upon a ground only slightly brighter looks almost as dark as the one upon perfectly white paper.

It is shown, therefore, that the small disks have suffered a change of brightness by contrast with the ground, and that the smallest perceivable difference in brightness between the two surfaces produces almost the same effect of contrast as that produced by the greatest contrast which can be conceived.

This remarkable "effectiveness of small differences" is of very great importance in painting; while from a scientific point of view it teaches us that the phenomena with which we are now dealing are of quite a different nature from the phenomena of successive contrast.

68. Simultaneous contrast a deception of judgment. The successive contrast asserts itself in a striking manner only when there is a considerable difference in brightness and in color between the ground and the object upon which the eye has been fixed, and it increases in vigor with the increase of this difference. Furthermore, to obtain the successive contrast it is absolutely necessary to fix the eye upon the object for some length of time, while the simultaneous contrast, as shown by the illustration just given, asserts itself at first sight. In this case, therefore, the idea of fatigue cannot be entertained, and we must consequently look elsewhere for an explanation.

The contrast between "light" and "dark" will be especially well fitted to serve as a clew in this matter. "Light" and "dark" are relative ideas, like large or small, loud or low, heavy or light, quick or slow. All these ideas are based upon comparisons with some object which has been accepted as a standard.

But for no species of quantities do we carry a fixed and invariable standard within ourselves, excepting perhaps for short lengths, which might be compared to the members of our own body.

As soon, however, as an object is not in close proximity, or

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as soon as it considerably exceeds the dimensions of our own body, we are extremely uncertain even in our judgment as to size, because this judgment is dependent upon all possible sorts of influences.

If, for instance, we see a person at a considerable distance walking across a level surface free from all other objects of comparison, say a very extensive meadow, we shall be absolutely unable to tell whether the person be large or small, or even whether it be a grown-up man or a child. If, on the contrary, a single object of comparison were present, our judgment would at once be influenced in a definite manner from which it would be impossible to escape. Presuming the person in question to be near a very large tree, the size of the tree, however, being unknown to us, we should undoubtedly be induced to suppose the person to be very small, since we attribute a medium size to all things of a certain species, as long as we are not informed to the contrary. In the same manner we should suppose the man to be much too large, if by chance he led an especially small horse.

It would be an easy matter to increase the number of similar examples, taken from various fields of observation, but we will now turn without further delay to that field which is at present of the greatest interest to us.

A piece of gray paper lying before a window in the full light of day may in reality be incomparably lighter than a sheet of white paper in the room, but still we shall immediately recognize that the one is gray and the other is white. We *suppose* the white paper in the room to be lighter, although in fact we see it much darker than the gray paper lying outside.

Thus an object will appear light to us if placed near a dark object suitable for comparison; but we shall take the same body to be dark when juxtaposed to a light object. The process is neither physical nor physiologic; it is a psychologic process.

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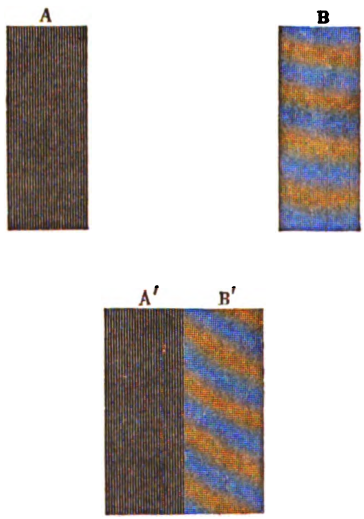
69. Contrast by juxtaposition. Our judgment in regard to similarity or dissimilarity in brightness is all the more certain the nearer the two surfaces to be compared are placed to each other, and the greatest degree of certainty is reached when the two touch each other directly. This is well shown by Fig. 48, which has been borrowed from CHEVREUL. The two

Fig. 48.



surfaces A and A' are shaded precisely alike; the same is true of B and B'. But while it is difficult to determine the difference in brightness between A and B, the difference between A' and B' is quite marked.

At the same time another peculiarity will be noticed. Each of the two surfaces touching each other looks as if it were shaded off towards one side, while in reality each is covered with a perfectly even tint. Furthermore, the brighter surface appears to increase in brightness, the darker one in darkness, towards the boundary line. It follows that the effect of contrast is strongest at this line. The name of

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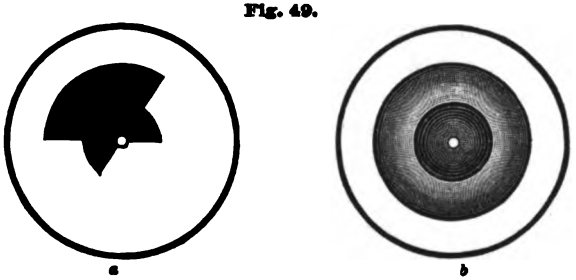
"contrast by juxtaposition" is therefore given to this class of phenomena.

This contrast by juxtaposition can be observed best of all by producing rings of a gradually diminishing degree of brightness upon the color-top, as shown by Fig 49 *a*. In this case each ring, when the disk is rotating, appears to be separated from the neighboring ring by a darker circle, so that the disk presents the appearance of Fig. 49 *b*.

Fig. 49.



In painting and in color-printing this contrast must be taken into account whenever it is desirable to avoid hard boundary lines between two neighboring surfaces. In painting it can be obviated by toning down on the side towards the boundary.

The contrast by juxtaposition does not belong exclusively to the category of simultaneous contrast, and is not therefore based simply upon a deception of our judgment, but it is also in great part caused by successive contrast. For whenever we look at an object we do not direct our eyes steadily to any one part, but we keep moving them about continually. When we turn our eyes from a darker surface to a lighter one, the image of the outer parts of the lighter surface must necessarily fall upon those parts of the retina which have just been exposed to the image of the darker surface, and which are therefore all the more sensitive to the new impression of light. Hence it follows that even from the effect of

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successive contrast the outer parts of the bright surface must appear brighter than the rest.

70. The most favorable conditions for simultaneous contrast.

Surfaces of different colors placed in juxtaposition will show phenomena which are perfectly analogous to those resulting from the juxtaposition of surfaces of different degrees of brightness. In such a case one color is likewise changed by another adjoining it, and indeed to such an extent that the difference between the two appears greater than it really is.

The experience which we have gained concerning the simultaneous contrast of light and dark can now serve us as a guide in our experiments on the nature of the simultaneous contrast produced by surfaces of different color. It is very natural to presume that the cause is the same for both kinds of phenomena, and that here as well as there we have to deal with a deception of the judgment. A more detailed investigation will show that this presumption is correct.

In making experiments on the simultaneous contrast of colors we shall therefore have to be careful to remove all those conditions which might be likely to aid us in forming an unprejudiced judgment of the nature of a color.

The contrast will assert itself much more powerfully, for example, if, besides the two contrasting colors, there is no third within the field of vision which might serve as a standard of comparison. It will be necessary, therefore, to place both colors upon a neutral ground, or, still better, to surround the one entirely by the other. In the case of pale, broken colors our judgment concerning their hue is more uncertain than in the case of full colors, and it follows from this that the former will suffer greater changes by contrast than the latter. Furthermore, it may be presumed, from the analogy of the phenomena described above, that small differences will show effects of contrast which are quite considerable, comparatively speaking.

Finally, the difference between two colors will also ap-

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pear to be greater than it actually is, when this difference alone marks the distinction between the two surfaces, without any aid whatever from other extraneous circumstances. The contrast may even be reduced by separating two colored surfaces from each other by means of a black outline. It is likewise less powerful when, instead of being painted with two pigments which are similar to each other in their nature, the two surfaces are painted with pigments exhibiting considerable differences in their properties, say, for instance, with a body-color and a transparent color.

Again, the contrast asserts itself more vividly with oil-colors than with water-colors, since the latter show much greater external differences, while the former are of tolerably even consistency.

The phenomena of contrast are most beautifully shown, however, by surfaces which are not painted at all, but which owe their difference in color to a difference in the illumination, as, for instance, in the case of so-called colored shadows.

Still, although it is true in general that painted surfaces are not as well fitted for experiments on contrasts as lights of various colors (such as are used in physical experiments), these contrasts nevertheless assert themselves very powerfully in painting proper. For here the form, or drawing, is of very material assistance to the judgment, and the contrast, aided by the illusion, can therefore show itself much more powerfully than when the two colors are simply placed alongside of each other in geometrical figures. Thus a light, perfectly neutral gray, in connection with yellowish white clouds, can serve to represent the most delicately blue ether, while a plain strip of the same gray, alongside of the same yellowish white, although still somewhat bluish, will not show this hue with near as much intensity as in the first instance.

71. Colored shadows. Having thus obtained a general idea of the various conditions here to be considered, we will

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now proceed to study more in detail the laws of the effect of contrast, for which purpose we shall have to make a number of experiments.

The simplest experiment of this kind is the one with so-called colored shadows.

Let us place some opaque object so that its shadow is thrown upon a white surface by ordinary daylight. Then place a candle upon the other side of the object, so that the light of the candle may produce a second shadow. It will be observed that this second shadow is blue, while the first is yellow.

The fact that the first shadow is yellow will hardly excite any wonder. For the place occupied by it, which was before protected from the light of day, is now illuminated by the yellow light of the candle. But the case is different with the blue shadow, which has only been called into existence by the candle-flame. The place occupied by it upon the white surface is still illuminated by daylight, and its appearance, therefore, ought to remain precisely the same, whether the candle be lit or not lit. And this is in reality the case, as can easily be proved by looking at the place in question through a narrow tube blackened on the inside. Seen through such a tube, by means of which we can so circumscribe the field of vision that it is confined to the place occupied by the blue shadow, while the adjacent parts which are illuminated by the yellow light of the candle are entirely excluded, and are, therefore, no longer available for comparison, the place will be found to be always of the same color, whether the candle-flame be present or not.

It is evident, therefore, that the blue color seen in the place indicated is only apparent, and that actually it does not exist. The spot occupied by the blue shadow is illuminated only by *white daylight*, the large white surface by *daylight and by candlelight*, the other shadow by *candlelight* only. It might be presumed, therefore, that one of the shadows would appear white, the other yellow.

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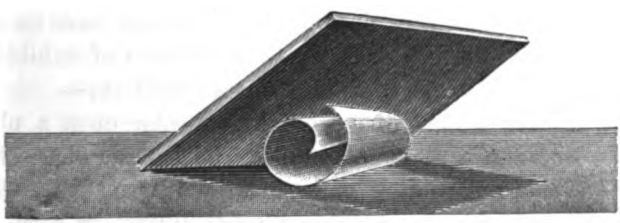
This is not the case, however; for, *knowing* the surface to be *white* in white light, we still take it to be white after it has really received the yellow light of the candle. Our judgment is led astray regarding white, and hence we believe the place occupied by the second shadow to be blue, although it is actually white.

If we employ a colored flame instead of the yellow light of a candle, the shadow thrown by daylight will appear in the color of the flame, while that thrown by the latter will show the complementary color. If the flame is red, the two shadows will be red and green; if it is green, they will be green and red. Instead of coloring the flame itself, which can only be done by means of various chemicals, the proceeding may be simplified by interposing plates of colored glass.

With the aid of such plates of colored glass, the experiments on colored shadows may also be easily carried out in another form.

If we place a good-sized plate of colored glass near a window, inclining this plate at an angle as shown by Fig. 50,

Fig. 50.



the surface beneath it, which must be covered with white paper, will be illuminated not only by the light entering through the window, which light will be colored, as it must pass through the plate of glass before it can reach the surface, but also by light reflected from the ceiling and from the walls of the room. An object placed between the plate of

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glass and the surface will therefore again throw two shadows, one of which shows the color of the glass, the other that of the complementary.

It will be of advantage to select some object for this purpose capable of throwing a shadow exhibiting considerable variety, as in such a case the color will show with greater intensity in certain places than in others. A half-opened roll of stiff paper will be found well adapted, and such a one has therefore been represented in the figure.

If the experiment is carried out in the manner described the paper will not, however, appear white. It shows the color of the glass employed, while the shadow which is turned towards the observer exhibits very vividly the color of the complementary, even if the second shadow is not seen at all. This experiment can be made to succeed exceedingly well by using a plate of blue glass. In this case the shadow turned towards the observer will exhibit a beautiful yellow of the color of sulphur, and, most curious of all, it will appear even lighter than the blue ground, although in reality it receives less light.

This paradoxical case is illustrated by the figure.

72. Contrast by reflection. In consideration of the great importance which the phenomena of contrast have for artists, we will describe several other methods of exhibiting them. The following is a very simple method:—

Lay a piece of glass of not too dark a color upon a plane mirror or upon a metallic reflector, and hold an object, best of all a thin rod, so that you can see its image in the glass (Fig. 51). In this case two images will always be seen, one the color of the glass, the other of the complementary color. This phenomenon may be explained as follows: One of the images, the apparent position of which is situated at *g* (Fig. 52), is caused by reflection at the upper surface of the glass, the other, apparently situated at *b*, by reflection at the amalgam surface of the mirror, or at the metal surface of the

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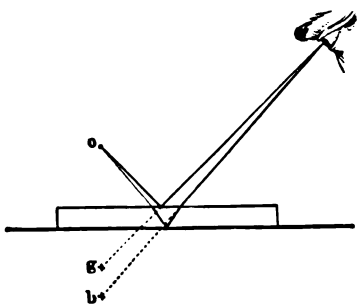
reflector. The latter image is produced by light which has passed twice through the colored plate, and must therefore

Fig. 51.

be intense in color; the former possesses in reality its natural color.

But as the observer does not *know* which of the two images is the colored one, he exercises his judgment, and divides between the two images the difference in color which really exists.

Fig. 52.



The experiment succeeds best when the plates are so situated as to reflect the clear sky, or, still better, the clouded sky, and the shaded side of the little rod.

Still another very simple and very beautiful method of showing the phenomena of contrast is the following:—

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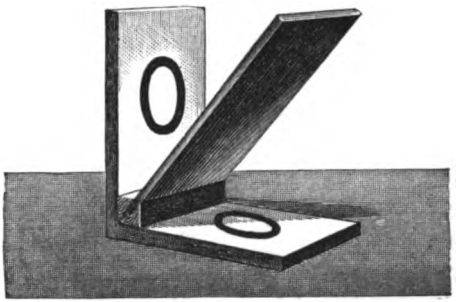
A plate of colored glass is so placed in an inclined position between two surfaces (white cardboard) fixed perpendicularly to each other, that the eye in looking through the colored plate sees the *horizontal* surface, while at the same time it perceives upon it the reflected image of the *vertical* surface (Fig. 53).

Fig. 53.



If we now draw a black figure, say, for instance, a tolerably broad black ring, upon each of the two white surfaces, it will be easy to find a position in which the reflected image of the figure on the vertical surface can be seen alongside of the one looked at through the glass, or in which the two will partially cover each other. It will be found that the reflected figure appears in the color of the glass, while the other shows the complementary color.

If the glass be green, the reflected image of the ring will also be green; the other ring, on the contrary, which is seen through the glass will be rose-color.

This most curious fact rests upon precisely the same deception of the judgment which we have met with in the experiment with colored shadows just described.

In reality, the ground upon which the two rings are seen is pale green, for the green light from the lower surface which has passed through the plate of colored glass mixes with the white light reflected from the upper surface. In the place where the black ring is reflected this white light is wanting, and from it the eye therefore receives only green light, while the black ring, which is looked at directly, emits no light at all, and consequently only the faint white light which is

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reflected from the front surface is sent to the eye by the points lying in this direction.

It might be supposed from this that a vividly green ring, together with a gray ring, would be seen upon a pale green ground. This is not the case, however, for our judgment again compels us to draw a false conclusion from which we cannot escape. We take the dominant color of the ground for white, or at least suppose it to be more whitish than it really is, and then charge the difference between its color and that of the actually gray ring to the latter, that is to say, we take it to be rose-color.

73. Influence of various degrees of fulness on contrast.

This experiment admits of a highly interesting and instructive variation.

If we replace the vertical white surface by one that is perfectly black, and if we then look at the horizontal surface through the colored glass, we shall observe not a trace, or at least hardly any trace, of the contrasting color. The ring appears perfectly black upon a green ground. But as soon as we exchange the black surface for one that is perfectly white, the contrasting color will immediately assert itself, although not as vividly as in the first experiment.

The intensity of the contrasting color which makes its appearance is materially influenced by the quantity of white light present. By turning the whole apparatus about, this quantity may be increased or diminished, and it is easy by this manipulation to find a position in which the proportion is the most favorable.

This experiment is exceedingly important, for it shows that no contrasting color can develop itself upon perfectly black surfaces, and that an admixture of white light is absolutely necessary to produce it.

If, however, the contrasting color is to assert itself vividly, it will not be sufficient to change the reacting black surface to gray by an admixture of white light, but a similar change in the inducing colored surface will also be found to be of advantage.

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This is best shown by drawing one of the rings in white on a black ground, and then placing the eye in a position in which the reflected image of the white ring will cover the black ring, which is seen directly. In this case the ring also appears in the complementary color, but the latter is not nearly as intense as when the whole of the reflected surface is white. This shows that the contrast asserts itself much more vividly with pale than with full colors. We shall subsequently see that the same rule applies to dark colors.

We may therefore lay down the following proposition: *Colors of a lower degree of fulness, that is to say, pale and broken colors, and colors inclining towards darkness, exhibit the phenomena of contrast more vividly than full colors.*

Full colors force their hue upon us so powerfully and so unambiguously, that no room is left for the deception of the judgment, which forms the basis of the phenomena of simultaneous contrast. (See also § 75.)

These observations will explain the important part played in painting by broken colors. Such colors do not exert the fatiguing effect of successive contrast; but they call forth, more than any others, the insinuating effect of simultaneous contrast, which is prolific of illusions. An artist who works with full, unbroken colors therefore deprives himself of one of the most potent means for producing illusions by the aid of simultaneous contrast. The paintings of such an artist will never produce the impression of richness of color, in spite of the lavish outlay of pigments. They will always look gaudy, poor, and hard.

The fact that the phenomena of simultaneous contrast will not appear very vividly unless there is an admixture of white light, may also be shown by still another method, which, although not as beautiful, has the merit of being very simple.

If we lay a small piece of black paper upon a colored ground, we shall at the best see only a very faint tinge of the

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contrasting color upon the black paper, especially if the latter is without lustre. But the contrasting color will be observed immediately, as soon as we cover the whole with a piece of transparent paper.

Instead of a piece of black paper we may also make use of black letters printed upon a colored ground. This plan has been adopted for Plates VI. to XI., which will explain themselves. The contrasting color may, however, be made to appear even without the intervention of white paper by so holding the printed paper that the black letters send reflected light to the eye.

This fact is of especial importance in weaving, for it shows that the difficulty of obtaining a pure black by means of threads will increase with the increasing tendency of the threads, and of the woven fabric, to emit reflected light. Black figures upon a violet ground, for instance, will show a strong tinge of yellowish green, if executed in satin, while in velvet they will appear of a much purer black.

To avoid this effect, it is necessary to give to the black a slight hue which will neutralize the contrasting color, that is to say, the black will have to partake somewhat of the color of the ground. If a purely black drawing is to be executed upon a red ground, a reddish black must be used; upon a blue ground a bluish black, etc.

74. Influence of various degrees of brightness on contrast. But in making these experiments the curious fact will be noticed that the various colors which may be given to the ground, or, to use an expression employed before, to the inducing surface, differ greatly in their capability of calling forth the contrasting colors. Green, blue, and violet, in fact, all the so-called cold colors, will originate very vivid contrasting colors, while this is the case to a much lower degree with red, yellow, and yellowish green.

Even the colored papers with printed letters upon them (Plates VI. to XI.) will suffice to show this. The contrasting

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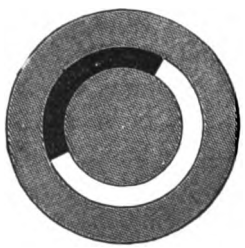
color can easily be made to appear upon the blue and the green paper; the red paper, however, already presents some difficulty, and in the case of the orange and the yellow paper this difficulty is still greater.

For the purpose of a more detailed investigation of this point, as well as of the dependence of the contrasting color upon the brightness and the purity of the inducing and the reacting color, we shall again make use of the instrument which has so often been of good service to us before, that is to say, of the color-top.

Let us place two disks of the same color, but of different dimensions, upon the color-top. Between these two disks let us place two others, the one white, the other black, both of them somewhat larger than the smaller colored disk, and arranged so as to overlap each other by means of a radial slit. (See Fig. 54.) We shall very naturally expect to see a gray ring upon a colored ground when the apparatus is in motion. In fact, however, we shall not see the ring gray, but it will appear to us in the contrasting color of the ground with an intensity dependent upon the proportion in which black and white have been mixed in the ring.

Fig. 54.



By changing the relative position of the apparatus to the windows, or by introducing white or black sectors, the brightness and the fulness of the inducing color can be varied at will, and the influence exercised by each element can thus be studied with the greatest ease.

It is indeed difficult to take actual measurements as to the composition of the gray best fitted to show the contrasting color; but we shall nevertheless soon observe that this color can be obtained most powerfully upon a blue field when the gray ring is lighter than the ground, upon a yellow field when

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it is darker, and that in the case of green and purple a medium degree of brightness is the most favorable.

This dependence of the intensity of the contrasting color upon the proportions of brightness in the reacting and the inducing surface may in a general way be expressed as follows: —

The contrasting color appears in its greatest intensity when the brightness of the inducing colored surface bears the same proportion to that of the reacting gray surface which the inducing color must bear to its complementary, if these two are to produce white when mixed together in a state of greatest possible fulness.

The relative degrees of brightness of the various colors which are here demanded have previously been designated as their "natural brightness" (see p. 117). The proposition just laid down might therefore be also formulated as follows: —

The most favorable conditions for producing the contrast upon a neutral gray field will be found to exist when the degrees of brightness of the inducing colored and of the reacting gray surface bear to each other the proportion which the degree of natural brightness of the primary (inducing) color bears to that of the contrasting color.

These propositions are in perfect accord with the view expressed above, that the simultaneous contrast is simply the consequence of a deception of our judgment. Being accustomed to look upon blue in general as darker than yellow, we shall be much more liable to take a dark gray surface, placed alongside of a yellow one, for blue, than a light gray surface, since in the first case the degrees of brightness mislead the judgment, while in the latter they assist it. The same is true of all other colors. A proper proportion between the degrees of brightness of the colored and of the neutral surface will always aid the illusion very essentially, and will influence the judgment in a definite direction.

As, generally speaking, the so-called cold colors are also

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the darker ones, while the warm colors are the lighter ones, the results obtained may also be condensed into the following statement, which will perhaps be more congenial to artists: —

Cold colors induce the appearance of contrasting colors of greater intensity upon a neutral gray surface when that surface is lighter, warm colors when it is darker, than the inducing color.

Thus a purely gray surface is made to look much more bluish by a whitish yellow placed alongside of it, than by a brown, while on the other hand a light gray is affected more by a strong blue than a very dark gray.

Still another phenomenon is very closely connected with the observations just made.

It has been shown above that the quantities needed of two complementary colors to produce white by their mixture differ greatly for different pairs of colors. A small quantity of blue, that is to say, of a very dark blue, is sufficient, for instance, to neutralize a very large quantity of yellow, that is to say, of a very light yellow, and the same observation is true of other pairs of colors.

Hence it follows directly from this that those colors which are naturally dark must produce contrasting colors which are much brighter than those produced by bright colors; for in the case of simultaneous contrast upon a neutral surface, and with correctly proportioned degrees of brightness, the two colors will always show themselves in the proportion in which they complement each other so as to form white. And remembering again that the dark colors are at the same time the cold colors, we can also say: —

The cold colors produce simultaneous contrast upon a neutral surface more strongly than the warm colors.

This may be one of the reasons why it is so much easier to obtain harmony and quiet with warm than with cold hues.

75. Diminished fulness favorable to contrast. The effect produced upon simultaneous contrast by a diminution in the fulness of the colors can also be studied very excellently by the

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method above described, whether this diminution be obtained by an admixture of white or by a reduction in brightness.

If the experiments are made in broad daylight, and with a ground of as full a color as possible, the contrasting colors upon the ring will be developed so weakly that an unpractised eye can hardly recognize them. If, on the contrary, the apparatus be brought to a dark corner of the room, or if it be so placed that the shaded side is turned toward the eye of the observer, the contrasting color will immediately appear very vividly. It may even happen, indeed, in very faint light, that the contrasting color upon the ring stands out sharply, while it is almost impossible to tell the color of the ground. This will be more especially the case if the inducing color has been selected from among the dark colors, thus making it necessary to keep the ring tolerably light for the purpose of producing the strongest possible contrast.

Very similar observations may be made with a ground containing a large quantity of white. If, for instance, we take a ground composed of one quarter of vermilion and three quarters of white, the disk, when rotating, will show a very pale red, which might easily be taken for white. But as soon as we fix a gray ring (best of all one eighth black, seven eighths white) upon the disk, according to the method previously described, the ring will immediately appear intensely green in color.

These experiments show that the eye is most sensitive to the contrasting colors in those cases in which, on account of the darkness or paleness of the colors, it is left in uncertainty as to the hue of the ground, that is to say, the hue of the inducing color actually present.

In the open air we can also easily convince ourselves that a definite medium degree of brightness is the most favorable for the development of the contrasting colors. On a sunny day the landscape generally shows but little color; but if we look at it on such a day through a very fine opening in a dark

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screen, such as can be obtained by pricking a hole through a blackened piece of cardboard with a coarse needle, we shall at once see a greater richness of color, and above all much more intense contrasts.

A black glass, leaving aside its peculiarity already alluded to, acts similarly.

Even fine white woven fabrics, spread out over a colored ground in the manner of a veil, may, under certain circumstances, contribute towards the heightening of effects of contrast.

76. Contrast between two colors.

The experiments thus far discussed relate only to the appearance of contrasting colors upon a neutral ground, and therefore to the *production* of color. The *changes* produced in given colors by contrast, that is to say, by the juxtaposition of other colors, remain still to be investigated.

For this purpose it will be best to employ colored papers without lustre, and it will be quite immaterial whether they are of very full or of very faint colors. From such papers, crayon papers, for instance, let us cut two kinds of figures, say, for instance, squares or disks of two different dimensions, so that we may be enabled to lay a small figure upon a larger one of a different color, and then to compare the colors of the smaller ones with each other.

If now we select any two colors for the larger figures and a third one for the two smaller figures, we shall, as a rule, find the color of these latter so changed, after having laid them upon the larger figures, that they appear to us to be no longer of one and the same color.

If, for instance, we take two disks, or, still better, two rings, of the color of red lead, and lay one of them upon a purple ground, the other upon a yellow, best of all a golden-yellow, ground (Dr. Schoenfeld's "gold-yellow" in medium thickness), the two will differ to such a degree in appearance that it is only possible to convince ourselves of their identity in color by removing them from the two grounds, and placing

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them alongside of each other. The ring upon the yellow ground has a more reddish look, that upon the red ground a more yellowish look, than is shown by either of them when seen upon a gray or a black ground.

If now we select for the ground two colors which differ still more from each other, and from the red lead, ultramarine-blue and green, for instance, the result will be similar in principle. The ring upon the blue surface has a more yellowish appearance than that upon the green surface.

This experiment which, as a matter of course, can be repeated with differently colored rings and with a suitable variation in the color of the ground, will aid us in formulating a proposition concerning the effect of one color upon another placed in juxtaposition. The complementary color of blue being yellow, and that of green being purple, the color of the ring (the reacting color), in the case under consideration, has received an admixture of the contrasting color of the ground (the inducing color). We shall see further on that this proposition can be generalized, and that we can therefore say briefly: —

If by the side of a given color we place any other color, the first will apparently be changed, as if some of the complementary of the second color had been mixed with it.

77. Influence of small differences.

This in itself correct proposition might, however, be easily misunderstood without an intimate knowledge of the law of mixtures. For it might be supposed that the magnitude of the change in color produced by contrast must grow with the difference between the two colors. It might be thought, for instance, that in the case cited above the change which the color of the red ring is subjected to must be much greater upon the blue and the green than upon the yellow and the red ground, since in the first case yellow and purple are directly mixed with the color of the ring as contrasting colors, and in the second green and turquoise-blue, which differ from each other comparatively

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but little. In spite of this, however, the contrary nevertheless takes place.

This we can readily see by proceeding as follows: Let us place the four squares which have served for a ground so that the purple will be situated above the ultramarine and the golden-yellow above the green, as shown by this diagram: —

Purple.	Golden-Yellow.
Ultramarine.	Green.

If now we lay rings of precisely the same color of red lead upon each ground, we shall notice immediately that the change in color by contrast is greater upon the two upper than upon the two lower squares.

Very similar phenomena will be observed, if instead of the red lead we select any other color for the reacting color, and then choose colors for the ground occupying the same relative position upon the color-chart to the new reacting color which those previously employed occupy to red lead.

It follows, therefore, that those hues which bear a closer relationship to the reacting color (the color to be changed) produce a greater change than those which are further removed from it.

This result, which is quite unexpected at first sight, will assume a still more stiking form if the experiment is varied as follows: —

It is self-evident that, instead of causing two surfaces of equal color to appear unequal by contrast, we can also cause two surfaces of unequal color to appear equal, provided that the difference between the two is not too great to be overcome by the influence of contrast.

Take, for instance, a small disk colored with red lead, and another colored with vermilion, and lay the former upon a yellow, the latter upon a purple ground (rose-lake in a thick layer, or purple-lake). By a little manipulation these hues can easily be so arranged that the two disks will look perfectly alike, and that an unprejudiced observer will see no difference between them. But if we now exchange the two

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disks so that the one colored with vermilion rests upon the yellow, and the other colored with red lead upon the purple ground, the difference between the two disks will be shown so strikingly that it will be almost impossible to believe them to be still the same, and that, when the change is rapidly executed, the experiment almost reminds one of legerdemain. This experiment is shown, although in a somewhat different form, by Plates III. *a* and *b*. It is excellently well adapted to show how existing differences may be increased or diminished by contrast.

The experiment is made especially instructive by the following variation: Again let us lay the two disks upon the purple and the yellow ground, so as to make them appear of the same color. If we now take the disk which rested upon the yellow ground and place it upon a green one, while the disk which lay upon the purple is transferred to an ultramarine ground, we shall recognize at once which of the two disks is colored with vermilion, and which with red lead.

That disk which, upon the yellow ground, looked quite as red as the one upon the purple ground, now has a yellowish tinge, while the other looks much more reddish upon the blue than upon the purple ground.

Although this fact is very curious, and although upon superficial examination one might easily suppose it to be in contradiction to the proposition advanced above in regard to the effect of simultaneous contrast, it will nevertheless be found, with the aid of the law of mixtures, to be a simple result of this proposition.

Let us suppose the reacting color (in the case under consideration the color of the disk) to be situated upon the color-chart at *M* (Fig. 55). If we now place alongside of this color a second situated at *A*, the influence exercised upon *M* by this second color will be the same as if *M* had received an admixture of the contrasting color of *A*, that is to say, of *a*. The intensity of this contrasting color will, however, be of a

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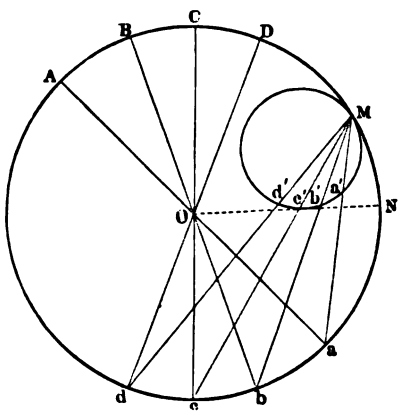
lower degree than that of the color which produces white with *A*, say, for example, half as low, and the mixed color must therefore be situated at *a'*. If, furthermore, we select successively for the ground, that is to say, as inducing color, the colors situated at *A B C D*, the resulting colors will be *a' b' c' d'*. The change in hue, therefore, reaches its maximum in the present instance when *C* acts as the inducing color, and the resulting hue corresponds to the point *N* upon the circumference of the color-disk. In the case under consideration purple would have been the color to exercise this strongest influence.

Fig. 55.



78. Influence of contrast upon fulness. The drawing given in Fig. 55 may serve at the same time to show that, besides a change in the hue of the color, there is also a change in fulness.

Although these two influences assert themselves in very different ways, it is nevertheless not difficult to gain an insight into the effect produced by them. The result which we shall arrive at may be expressed about as follows: —

By the juxtaposition of its complementary a given color gains in fulness. By the juxtaposition of another color its hue is changed, so that the difference between the two appears to be greater than it really is.

Or, in other words: —

By the juxtaposition of a second color a given color is shifted in the scale of colors, so that the distance between the two upon

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the color-chart (in the cone of colors) is increased. This shifting reaches its maximum at a definite, moderate distance between the two colors. With every increase of the interval between the two colors, the distance to which they are shifted apart, that is to say, the change in hue which they undergo, is lessened, but at the same time the strength of both colors is increased, they gain in fulness and intensity. This intensification reaches its maximum when the two colors are complementaries. In a more condensed form this proposition might be expressed as follows: Greater intervals intensify and strengthen the colors placed in juxtaposition; moderate intervals shift them apart.

Artists generally express this proposition as follows:—

The colder colors make a neighboring color warmer, the warmer ones, on the contrary, make it colder.

This proposition, according to which the influence exercised by one color upon another is more powerful in the case of moderate than of greater differences, is practically of the very highest importance, and all the great colorists have actually made extended use of it; while bunglers, who are led by the trivial idea that "much helps much," will always endeavor to reach their aim by strong contrasts.

We have seen that small differences in brightness cause very successful effects of contrast; we have also seen that colors of a low degree of fulness originate more vivid phenomena of contrast than those of a higher degree; and we see again in the present instance that the same is true in regard to the change in the hue of the color.

We are indeed moving upon a territory here upon which homœopathic doses are indicated, and where small means produce a more powerful effect than large means. Nowhere is a wise economy more in place than in painting, since all violent efforts appear to interfere with and to destroy each other.

It may appear strange that, in spite of these observations, full colors have been selected for making our experiments on

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the shifting of hues in the scale of colors. The only reason for doing this is to be found in the fact that we have no simple names for broken hues. In reality these experiments succeed much more strikingly with such hues, thus showing that the conditions prevailing here are again similar to those which we observed when investigating the phenomena of contrast on a neutral ground.

From the experiments last described it might be very natural to suppose that of the two colors concerned one only underwent a change. This is not the case, however. On the contrary, both colors are affected, as if each had received an admixture of the complementary of the other. But the extent of this change differs with external circumstances, and the difference is indeed often so great that in many cases one of the two colors may be looked upon as invariable, and the whole of the change may be attributed to the other.

79. Contrast influenced by size and shape. The form as well as the size of the colored surfaces exercises a material influence in determining which of the two colors is to be shifted farthest from its original position in the scale of colors.

Whenever a small colored surface is completely surrounded by a larger one, as in the experiments described above, in which we made use of a small square or disk upon an extended colored ground, almost the whole of the change falls to the share of the former, while the ground retains very nearly its original color. In Fig. 4 on Plate V., for instance, the red is very materially shifted towards the yellow by the surrounding blue; while in the latter, which is the dominant color and which occupies a considerably larger space, hardly any change is noticeable.

80. Influence of borders on contrast. There are still other secondary circumstances upon which the success of the contrast depends. A line separating the two colored surfaces may almost neutralize their effect upon each other, while a more complicated border acts still more powerfully in the same

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direction. This is very well shown by Figs. 1 and 2 on Plate V., in which the red and the blue, being seen alone, assert themselves to their full value, while in all the other figures they are materially modified, partly by mixture, partly by contrast.

81. Summary. Reviewing the various effects which simultaneous contrast is capable of producing, we shall find that:—

By contrast colors can be produced where none exist, that is to say, upon a neutral surface; furthermore, colors can be changed in hue; and, finally, their brightness and their fulness can be heightened or lowered.

The painter avails himself of the effects of contrast in all these directions. The decorative artist, however, makes but little use of the change of hue by contrast, that is to say, of the shifting of the hue in the scale of colors, since this shifting is always accompanied by a lowering of fulness, and since fulness of color is precisely that quality which is most admired in ornament. Those combinations, in which the shifting of the colors reaches its maximum, are therefore called bad combinations in the decorative arts, and the contrasts which are caused by them are called injurious contrasts. The heightening of brightness and of fulness by contrast is, on the contrary, employed very extensively in the arts just named.

The whole of the theory of the combination of colors in works of art, which the next chapter is to treat of, will in great part be simply a practical application of the theory of contrast.

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FIFTH CHAPTER.

THE COMBINATION OF COLORS.

82. Difference in the position of color in ornamental art and in painting.

THE several arts which address themselves to the eye through color employ the latter according to principles which differ widely from each other. While in the decorative or ornamental arts color occupies an independent position, the place assigned to it in painting is rather secondary.

The uses made of color for decorative purposes are based essentially upon the delight in color as such which has been implanted in man by nature. Even the child gathers colored pebbles, takes pleasure in bright flowers and brilliant feathers, and man in his first attempts at industrial art employs these same means for the embellishment of his creations.

Bodies which are naturally colored possess a greater commercial value for this very reason. The jewel is esteemed simply for its color, or for the play of colors exhibited by it, and immutability and rarity are certainly not the only qualities which have enhanced the value of gold in the eyes of men. The color which distinguishes gold from all other metals has had quite a large share in securing for it the position it now holds.

Materials which by nature are colorless, or which possess only a dull color, are dyed, so as to make them partake of this coveted superiority.

The desire to enliven objects by means of color, to give

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them a pleasant and attractive appearance, is a distinctive mark of the whole body of decorative and ornamental arts.

In these arts color is valued for its own sake; here full and strong colors are demanded, which in this connection are frequently designated simply as "beautiful" colors, and the splendor of which is often heightened by combining them with gold and silver. Here the color never aims (or at least never ought to aim) to hide the material to which it is affixed, but endeavors, on the contrary, to beautify it, and to present it to the eye in an ennobled form.

In painting, however, the case is quite different. It is the painter's aim to imitate certain given objects upon a plane surface, and to express an idea by such imitation. In the painter's hands color, far from being its own object, is only a means to an end.

The principles, therefore, according to which colors are employed and combined in the decorative arts differ very decidedly from those which obtain in painting. While the material is shown in the former, while there is a special predilection for the employment of costly substances, and for the development of splendor and riches, it is, on the contrary, the painter's most assiduous endeavor to cause the material with which he works to be forgotten.

Looking at a picture we desire to be reminded as little as possible of the fact that it is executed with pigments upon canvas, wood, or paper. For the painting is to transport the mind of the beholder to another place, to other times, and perhaps even to another world.

It is for this reason that a painting is isolated from its surroundings by a frame, the isolation being all the more complete, the more perfect the manner in which the painting is executed. Thus we employ gold frames for oil-paintings; white panels with fine lines for water-colors; and painted borders, which act as mediators and serve to keep up the connection with the architectural surroundings, for frescos.

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But in every one of these cases the endeavor is always to divest the surface bearing the picture of the character of a plane surface, while in the decorative arts the plane as such must be allowed to assert itself.

The remarks just made will be sufficient to show how widely the two branches of art under consideration diverge in their aims.

In accordance with these facts, the means employed by the decorative arts and by painting are likewise very different, and it is therefore absolutely necessary strictly to separate the two departments when endeavoring to discover the laws of the combination of colors, and to study each of them in that phase which presents its most characteristic development.

As such extreme types we may on the one hand regard the weaving of colored stuffs, and the decoration of walls and floors, which is next of kin in style to weaving; on the other, oil-painting, and more especially the portrait. While a woven fabric shows the character of a plane surface in the most pronounced manner, and gives the widest scope to color as such, oil-colors offer the best means for the imitation of natural objects, which imitation finally culminates in the portrait, as the closest possible rendering of nature.

As a matter of course there is no lack of connecting links between the two extremes, from the carpet bestrewn with flowers, and the wall ornamented with garlands of foliage, in which the representation of natural objects mainly serves a decorative purpose, to the gobelin and the fresco, which latter, although a painting, is nevertheless an integral part of the building, and ought never entirely to disown its character as a mural decoration.

But in spite of these manifold varieties it will be easy enough to discover the leading principles, when we have once succeeded in finding them for the extreme cases. We will therefore begin by observing the combination of colors in simple patterns, more especially in those produced by the

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Orient in silk and in wool, in mosaic and in enamel, or for mural decorations; and from these we will proceed to the principles which apply to painting proper.

A. — THE DECORATIVE OR ORNAMENTAL ARTS.

83. Aim of ornamental art. It is the task of decorative art to enrich and enliven the objects of daily use by the addition of new forms and of colors which exceed the limits of absolute necessity. The desire for such embellishments is visible even in the simplest products of human industry, and it is more particularly the study of these simplest products which is best adapted to give us an insight into the very essence of the nature of ornament. We shall learn from this study that all ornaments owe their origin mainly to technical necessities.

By executing the seam, which is absolutely necessary to protect the woven fabric against wearing off at the edges, in regular stitches, or, still better, with a thread of a different color, we convert it at once into a simple ornament. By purposely taking out those threads towards the edge of a woven fabric, which would fall out of themselves if the fabric were used unseamed, and then transferring the seam farther towards the centre, we add a new decorative element, — the fringe.

By simple means like those just described the savage tribes set off and beautify the products of their industry, and a detailed study of these beginnings of art shows that all ornaments, even those which were used during the epochs of greatest development, owe their origin to the same simple elements. In such a study no better guide can be found than SEMPER'S masterly work on "Style."

The primitive ornaments, presented to us by these incunabula of art, although frequently very imperfect in execution, generally make an impression upon the beholder which is quite satisfactory and harmonious from an æsthetic point of view.

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The reason for this will be found in the simple fact that there is an intimate and easily discernible connection between the ornament and the object which it is destined to embellish, — a connection similar to that which we admire in the productions of living nature, and which is therefore quite correctly called an "organic connection."

84. Principles governing the coloristic treatment of ornaments.

This observation will at the same time furnish us some valuable hints regarding the coloristic treatment of an ornament. As long as such an ornament is perfectly free from any imitation of natural objects, as long as we are concerned only with a purely geometrical pattern or with a so-called arabesque, there is left to us a large measure of liberty in the choice of colors; and such ornaments are therefore better fitted than any others for the purpose of investigating the laws of the harmony of color proper. These laws and rules culminate in the simple proposition that there subsists an organic connection between form and color similar to that subsisting between the elements of form in the ornament and the object which the ornament is to embellish.

There must be a rational organic connection between the color and the form and essence of the whole work of art. This first and simplest rule cannot be recalled often enough to the mind of the artist and the artisan. The observance of this simple and indeed self-evident proposition is the characteristic mark of the best and most flourishing periods of art; its disregard is the sign of decay.

In a somewhat different form this proposition may be expressed as follows: *The color must be adapted to the form.* Thus worded, our proposition is capable of further development, and will lead us to a division of ornaments into two essentially different groups.

85. Co-ordination and subordination.

An ornament is either composed of elements which are *equivalent* to each other, both as to space and to artistic importance, or of such as

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differ in size and in shape, some of which therefore play a prominent, others a subordinate part. Elements of this kind are consequently *not equivalent* to each other.

Ornaments of the first class are formed upon the principle of *co-ordination*, those of the second upon that of *subordination*.

86. Elements of form of different orders.

Before proceeding we must examine somewhat more in detail into the conception of equivalent elements of form, and of such as are not equivalent.

The combinations of equivalent elements are quite limited in number, and embrace only the simplest patterns that can be imagined.

Bands of equal width, triangles, quadrangles, and hexagons of equal size, the sides of which may, however, be also conceived of as curved, are the only geometrical figures of which such patterns can consist.[14] Regular octagons already necessitate the presence of other elements, of quadrangles, namely, for the formation of a pattern. In combinations confined entirely to equivalent elements the greatest and most unlimited scope is allowed in the choice of colors. But by introducing different colors we immediately also introduce a new design into the original, simple pattern, and the elements which at first were equivalent are deprived of this character by a definite distribution of color. In such cases it is the color which supplies the design, as in all mosaics composed of pieces of equal size and equal shape.

It is different with those ornaments the ground-form of which shows elements of different orders. The construction of such ornaments already exercises a tolerably definite influence upon the choice of colors. An example will serve to elucidate this point, and at the same time to show what is here understood by "equivalent" and "not equivalent," as well as to make apparent the importance which attaches to this division.

Fig. 56 represents part of a mosaic on a wall in the cathe-

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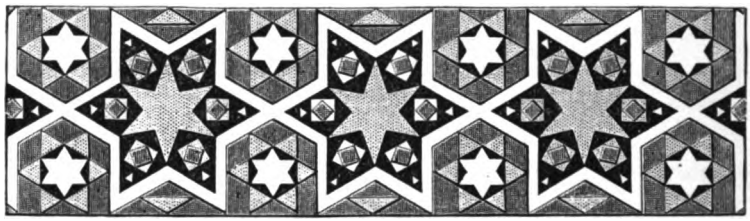
dral at Monreale. Hexagonal stars are surrounded by a white band, which latter at the same time connects the individual

Fig. 56.



stars with each other. The stars are placed upon a red ground, this color being indicated in the figure by vertical lines, while gold is indicated by dots, black by black, and white by white.

In this mosaic the white band as well as the large and the small stars are recognized at once as elements of different orders, the relative importance of which will have to be emphasized by the choice of colors. By this choice the ornament itself can also be made to undergo a change in its ground-form.

If we look at the design only, without regard to color, all the large stars will present themselves as equivalent elements; and if we should really give the same color to all of them, the whole arrangement might be characterized by the following formula:—

A A A A ....

But if we give one color to the second, fourth, sixth star, etc., and another color to the first, third, fifth, etc., we shall obtain a row of alternating elements, which might therefore be designated by

A B A B A B ....

It will not be necessary in this case to give to each star A, throughout its whole body, a color different from that of the stars B; on the contrary, a variation of some one part will be sufficient to give a different appearance to the whole star.

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In the ornament, for example, which has been selected as a starting-point, and which is represented by the figure, the whole of the difference consists in this, that in the middle star the corners in the small quadrangles which are grouped around the inner golden star are white, while in the two neighboring stars they are gilt. But this little variation is quite sufficient to impart a different appearance to the whole of the middle star, and to give to the entire row of stars the character of the formula: —

A B A B A B . . . .

A new enrichment might be introduced into the ornament by coloring the stars in three different manners, corresponding to the formulas: —

A B C A B C A B C A B C . . . .

or

A C A B C B A C A B C B . . . .

These two arrangements, however, again show an essential difference. In the first case, although the stars are not all perfectly alike, they still appear to be equivalent, as the colors always recur in the same order. But in the second case a prominent part is played by the stars C, because they now appear as the centres of two different groups, namely, A C A and B C B. The principle of co-ordination, according to which this ornament was originally constructed, has therefore been destroyed by the distribution of colors here chosen, and the principle of subordination has been introduced instead.

But if this is to be the case, the new principle must also find its expression in the choice of colors, and the stars which now occupy an exceptional position will have to be specially emphasized by the color.

While therefore the colors red, green, and blue, for instance, can be employed for the formula A B C A B C A B C, it might perhaps do to select two of these colors for A and B in

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the formula A C A B C B A C A B C B; but for C we should have to select gold or silver, or white or black, instead of a color proper, so as to distinguish these stars from the others.

At the same time, however, we must not forget that a color which of itself does not play a prominent part in an ornament may assume such a part by virtue of the special relations which it holds to its surroundings. An ornament, for example, which, either as a frieze, a border, a hem, or seam, etc., surrounds a surface showing some prominent local color, may contain an element of the same color. This fact, which places the element in question into relation with something outside of the ornament, is sufficient to give a dominant position to this element, and therefore to change the whole character of the ornament from that of co-ordination, according to which it was originally constructed, to that of subordination.

This example will undoubtedly suffice to elucidate the meaning of the words "equivalent" and "not equivalent," "co-ordination" and "subordination."

Those elements of a design which are entirely different from each other in form may also very aptly be called elements of different orders.

Surfaces and lines, for instance, are such elements of different orders. From this it does not follow, however, that surfaces may not again be of very unequal value among themselves, since they may serve as a ground, or may be larger or smaller, etc. The lines, on the other hand, may at one time appear as bands, at another as mouldings, then again as curves, or finally as simple outlines bordering a surface.

87. Colors of different orders. A division similar to that just indicated for the elements of form may also be made in respect to colors.

But in making this division it will be absolutely necessary to admit into the sphere of our discussion, not only the poles of the system of color, that is to say, black and white, but also gold and silver, all of which we will designate as "decorative

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means of the first order," so as to avoid too violent a conflict with the ordinary usages of the language of physics.

If we now endeavor to arrange into a system the various colors, together with the decorative means just mentioned, which latter are closely allied to colors in the manner in which they are applied, we shall obtain the following groups: —

FIRST ORDER: *Gold* and *silver*, *black* and *white*. White frequently takes the place of silver, while in many cases *yellow* is used instead of gold. But in that case yellow must simply be looked upon as a substitute, and must not be treated as a color proper.

SECOND ORDER: All the *full* colors, that is to say, the colors of the spectrum and purple in their medium (natural) degree of brightness. These are represented by what are usually known as high colors, or, in other words, by the strongest pigments. It may also be said that this order comprises all the colors situated upon the circumference of the color-chart.

THIRD ORDER: This order is itself subdivided into three groups, all of which rank below those mentioned above in strength of impression, but which are tolerably equivalent among each other. These three groups are the *dark*, the *light* and *pale*, and the *broken* colors.

The *dark* colors are situated upon the outer surface of the cone of colors towards the apex. They are pure, but of a low degree of luminosity.

The *light* and the *pale* colors are produced by the mixture of pure colors with white. Their position is in the central portion of the color-chart, that is to say, upon the ground surface of the cone of colors.

The *broken* colors, finally, are the pale colors in a low state of luminosity, the transitions from the full colors to pure gray, those colors to which we have assigned the interior of the cone of colors.

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Within each of these groups there is still a wide range of hues and tints, which differ greatly from each other in the intensity of the effect produced by them on surfaces of equal area and equal shape, and which are therefore far from being equivalent, so that a rich chromatic composition is still possible, even when the choice of colors is confined to one order or group.

88. Polychromy and monochromy. A chromatic composition in which different hues are employed is called *polychromatic*. A composition which is confined to the different shades of one hue, to which might perhaps be added black and white, as extremes, is called *monochromatic*. BRÜCKE makes still another difference between isochromy, when all the shades are of precisely the same hue, and homœochromy, when neighboring hues are admitted into the composition; but we shall make no use of these terms.

Polychromy, as it was practised throughout antiquity, reached its highest point of development among the Mahometan nations and especially among the Moors of Spain, and is still practised in the Orient to-day, depends mainly upon the two first orders. The dark, light, pale, and broken hues are employed but little in polychromy proper. The next lower order in the scale is only descended to when the materials with which the artist works are not found in full colors in their natural state, as, for instance, in the case of the cheap colored stones which are used for mosaics.

A simultaneous application of the elements of color of all the three orders is hardly ever met with, even where polychromy is employed in its richest development. Should it be found desirable to introduce dark, light, pale, or even broken hues into a polychromatic design, for the execution of which the means and colors of the first and second order are at command, this will be best accomplished by covering a colored ground with a design in another color made up of fine lines. If in a woven fabric, for instance, there occurs a blue

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band or stripe, which in one place is to appear of a paler, in another of a darker shade, it will be best to execute a white drawing upon the blue ground in the first case, and a black one in the second. The effects obtained would be similar to those shown by Figs. 7 and 8 on Plate V.

The method of producing half-hues by the introduction of smaller elements of form in another color is the only one which is admissible in polychromy proper.

It offers the only guaranty against heterogeneous hues, and assures the attainment of a unity in character which can never be lost entirely, even after the colors have faded.

89. Combination of elements of color of equal value. It is questionable whether the effort to lay down further similar rules of broad application can be successful, since the rule given by FIELD, according to which polychromatic designs must be so colored that the mixture of all the colors contained in them will produce white, has shown itself to be utterly untenable (see § 59).

We will rather endeavor, therefore, to penetrate somewhat more into details, and to find some hints regarding the combination of definite colors. But in doing this we must never lose sight of general principles. Hence in all cases in which the combination of two or more colors is spoken of without qualification, these colors will have to be conceived of as being applied to equivalent elements of form. We will also call attention to the fact that the names of colors must always be understood to designate the fullest possible colors in their natural brightness, that is to say, the colors upon the circumference of the chart, unless the contrary is especially stated.

If we now select any one color as our starting-point, and if we ask what other colors will furnish useful combinations with the one given, we shall arrive at a very curious result.

For we shall find that with each color we can combine those which occupy the position next to it on the color-chart, but

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that we shall obtain very bad combinations as soon as we leave the immediate neighborhood of the starting-point, until in the course of our movement along the circumference of the color-chart we shall again meet with better combinations, and shall finally reach the most effective of all.

The correctness of this proposition can best be made evident by studying some particular case. Let us try, for example, what colors can be combined with vermilion, and let us therefore group together with this color in succession all the hues of the color-chart divided into twelve parts (see § 56). We shall find at once that the combination of vermilion with orange is not favorable, that yellow is still worse, while yellowish green is already tolerable, and that, as we advance in the same direction, the combinations continue to improve. A similar observation will be made when we investigate the colors on the other side of our starting-point. Vermilion does not form an especially good combination with carmine, still less so with purple, while the combinations of vermilion with purplish violet and bluish violet are already sensibly better, until finally we reach a decidedly good combination when we come to ultramarine.

If we commence at any other point of the color-chart, the result will be similar. We shall always find that the combination of two hues cannot be called good unless these hues are at least four intervals apart from each other on the color-chart of twelve divisions, that is to say, unless at least three hues intervene between them. The worst combinations are obtained when the distance between the hues amounts to only two intervals, or, in other words, when only one hue intervenes between the two.

90. Combinations of small intervals.

Confining ourselves to still smaller intervals than those which the color-chart of twelve divisions can furnish to us, that is to say, conceiving the color-chart to be divided into a larger number of hues than twelve, say thirty-six, perhaps, or forty-eight, or even

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still more, we shall find that the neighboring hues agree quite well with each other. Of hues which are nearer to each other than the contiguous colors on the chart of twelve divisions, we shall in future say that they form *small intervals*.

An extensive use is made of combinations of such small intervals in the decorative arts, especially in mural decoration, in the manufacture of paper-hangings, in weaving, and in the ornamentation of porcelain, glass, or clay. Very frequently the same effect is also reached with only one color by the peculiar treatment of the material of which the object is made. This is the case, for instance, with damasks of one color, in which the unequal amount of superficially reflected light relieves the design from the ground, and at the same time imparts a tint to it, which latter forms a small interval with the tint of the ground. The same remark applies to hangings of pressed leather, and in general to all cases involving a low relief.

The investigation of these cases is of importance, as it will enable us to comprehend the manner in which small intervals may be turned to account. Wherever these intervals are made use of, they do not indeed enter into the composition as two different colors, but rather only as modifications of the same color, so that the whole surface appears as if it were animated by a sort of low relief. The drawing of the ornament must therefore assist this conception, and as a consequence we shall most frequently see the combination in question employed in the imitation of the manufactures named above, in which case the harmony existing between form and color becomes evident of itself.

We must, however, pay attention to still another peculiar circumstance when making use of the combinations of small intervals. For although we may justly say that these combinations are always admissible, we must nevertheless bear in mind that this is the case only when there is a certain very definite relation between the degrees of brightness of the two colors.

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An excellent effect, for instance, would be produced upon a vermilion or scarlet ground by a pattern of a darker red, approaching at the same time nearer to carmine. A drawing of dark vermilion, on the contrary, or of a reddish brown corresponding to vermilion, upon a carmine ground, or, still worse, upon a rose-colored ground, would be abominable. Again, a yellowish brown alongside of orange is exceedingly ugly, while a darker orange produces a good effect by the side of a lighter golden yellow.

If a cobalt-blue surface is to be ornamented by a dark blue design, it will be unsuitable to employ a greenish blue; but we shall have to select a blue which is nearer to ultramarine.

Whatever color we may choose, we shall always meet with the same connection between brightness and hue, a connection which may be expressed in the following proposition:—

In combining colors which are very closely related to each other, it will not do to combine a DARK *shade of a* BRIGHT *color with a* LIGHT *shade of a* DARK *color, but the bright color must always show as the lighter, and the dark as the darker of the two.*

This proposition may be expressed in a still simpler form, although it will not then be so general in its application, and will be subject to some exceptions. So formulated it will read:—

Excepting the small intervals between blue and violet, as well as between orange and yellow, the warmer hue will also have to be the lighter hue whenever contiguous colors are combined with each other.

The contrary rule governs the exceptions cited above. The reason for these exceptions will be found in the fact that the brightest and the darkest place in the color-chart does not coincide with the warmest and the coldest colors.

The method for turning the small intervals to account, which we have just discussed, is not, however, the only one possible. For we can also find combinations of such colors,

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in which the leading idea is just the reverse of that which prevailed in the cases cited above. If, for example, we are compelled to work with a material, which offers but few shades, and if we nevertheless desire to enliven our design by color, as in the case of mosaics in wood or straw, or of objects in gold, our effort must necessarily be to make existing differences appear greater than they really are. In such instances the areas assigned to the various hues must be so chosen that the contrast can exercise its full effect, or suitable outlines must be introduced to separate surfaces, which otherwise might appear to be alike. In both cases form and drawing must come to the aid of the imagination, to conjure up the illusion of a rich variety of colors.

But here we are already trespassing upon the province of imitative art, or of painting proper, which is governed by laws different from those so far discussed. All the combinations just alluded to, in which the small interval may indeed be exceeded with propriety and in which even those combinations will be admissible which would otherwise be called bad, must besides be justified by the material, the nature of which must serve as a sort of excuse for them. It follows from this that they are very apt to become dangerous in imitations.

91. Bad combinations. The combinations of hues which are somewhat farther apart from each other than the small intervals, but which are nevertheless separated by only a few of the intervals of the color-chart of twelve divisions, are of an entirely different nature, and produce a decidedly unfavorable impression. Vermilion and yellow, yellow and green, green and turquoise-blue, turquoise-blue and bluish violet, bluish violet and purple, purple and vermilion, are bad combinations. What are the reasons for the very evident displeasure which we experience when looking at these combinations?

The observations just made regarding the employment of small intervals may help us to find a correct answer. We

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have seen that colors which differ but very little in hue are treated in the composition as modifications of the same color, but not as elements of essential difference.

As soon, however, as we exceed such a small interval without choosing an interval which is considerably larger, the beholder finds himself in a peculiar predicament. The two colors are too far apart to allow of their being conceived of as a unity, and they are yet too nearly related to each other to be recognized as completely different and individually legitimate parts of the whole. Such an indecision in regard to the part falling to the share of an individual constituent of a work of art must at all times produce an unfavorable impression. It is easy to bring forward proofs of the correctness of this assertion from all departments of art.

By way of example we need only recall to ourselves the fact that small differences, so long as they do not obtrude themselves upon the eye of the beholder, are admissible even in the several parts of a building, although these parts, in accordance with the fundamental idea, ought in reality to be perfectly alike. Pillars, for instance, which, strictly speaking, ought to be of equal breadth, may vary somewhat, provided that there is a reason for such variation, or that it is concealed; upon a slightly inclined territory, mouldings which in fact ought to be horizontal may be given a slight inclination, so long as they leave the observer's mind free from doubt as to their horizontal direction; and examples similar to these might readily be multiplied.

In music it is similar. Upon keyed instruments and the instruments in orchestras, all of which are tuned according to what is known as the "equal temperament," the notes C sharp and D flat, or F sharp and G flat, etc., which in reality ought to differ from each other, are treated as if they were identical; that is to say, a mean note is sounded for them. But in spite of this compromise, even a musically highly educated ear is not offended by the resulting impurity of the intervals, as long

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as the composition makes it clear beyond doubt which of the two notes in question is meant. If, however, these two notes were sounded together, which would exclude all possibility of identifying them, the impression produced would be abominable.[15]

Besides this purely æsthetical reason for the dangerous character of *moderate intervals*, — for so we will call them to distinguish them from the *small* intervals, — there is also still another reason of a purely physical nature. In such combinations the two colors so influence each other by contrast that the fulness of both is reduced, and this kind of contrast has therefore very properly been called *injurious contrast*.

Another peculiarity of the bad combinations just spoken of, which can easily be observed, is the following: These combinations grow still worse when the relative degrees of brightness of the colors are so changed that the one which in its natural state of brightness is the darker of the two appears as the lighter. Light blue alongside of dark green, for instance, is much more insufferable than dark blue by the side of a lighter green, and the same holds true of light purple and dark vermilion, etc. In short, unnatural conditions in the brightness of the colors make bad combinations still worse.

These combinations improve when the degree of brightness is low, an evidence of which may be found in the blue and green Scotch plaids. In spite of all changes in the dominant fashions, these fabrics have always managed to hold their ground.

But the same combinations become absolutely unbearable when pale colors are employed, as in that case the injurious contrast exercises its effect most powerfully, and causes the most unpleasant impressions.

92. Refutation of Field's theory.

It remains for us to examine the most important of all combinations, those namely of hues which are far apart from each other in the scale

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of colors. But before doing so we must once more allude to a theory of which we have already spoken in a previous chapter.

We have seen (§ 59) that the leading principle which must be followed in combinations of this kind was formerly supposed to be known. The most favorable impression was believed to be obtainable by employing the colors in quantities so proportioned that their mixture would produce pure gray. The incorrectness of this supposed principle has been shown in detail in the paragraph above referred to.

It will always remain incomprehensible that even a man like OWEN JONES, in the text accompanying his beautiful "Grammar of Ornament," should have adopted this proposition in the form given to it by FIELD, since among all the ornaments reproduced in the work just mentioned there are scarcely any which really show the distribution of colors demanded by the proposition in question.

It is impossible, even by the most attentive search among the chromo-lithographic plates of the "Grammar," to find any considerable number of examples of the pretended best combination, or, in other words, of ornaments in which the areas assigned to blue, red, and yellow are as 8 to 5 to 3. Only a very few of the Egyptian ornaments answer to this rule, and these only to a certain extent.

93. Combinations of complementary colors. It will therefore be absolutely necessary to look about for another rule.

Having once abandoned the idea of unity of color, which served as the leading principle in the employment of small intervals, our efforts must evidently be to give a decided expression to the new principle adopted, that is to say, the principle of variety.

For such combinations we shall therefore have to select colors which are separated from each other in the scale of colors as far as possible, although there will of course be a great difference in the distances between the various colors

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chosen, as these distances must necessarily depend upon the number of colors introduced into the composition as equivalent elements. I say purposely *in the scale of colors*, and not *upon the color-chart*, for if we were to choose the latter mode of expression we would thereby demand that, in the combination of colors in pairs, the two colors must be complementaries, which would after all bring us back to FIELD'S rule for the combinations under consideration.

And indeed the idea is very frequently met with, that the combinations of complementary colors are the best. An attentive study of the most beautiful ornaments of the best periods of art does not, however, bear out this idea. But in entering upon such a study we must never forget what has before been said concerning the equal value of the elements of form. Take, for instance, a Moresque ornament divided into equally large panels of equal shape, painted alternately red and blue, and the whole imbedded within a network of golden lines. In this case it would be totally incorrect to speak of a triad of colors, for here we have a pair of colors, blue and red, ornamented with gold. Gold, or the yellow representing it, enters into the composition in a manner very different from that in which blue and red enter into it.

Keeping this point in view we shall find that pairs of complementary colors are indeed never absolutely contrary to good taste. But we shall also find that they are frequently very hard, and that only a few of these pairs are employed in exemplary works of art, while others are always avoided. The combination of blue and yellow, for instance, especially of turquoise-blue with yellow, is far from being elegant, unless the yellow be replaced by gold. The combination of vermilion with its complementary bluish green is also very hard.

The combinations of red and blue and of violet and yellow, both of which have at all times been favorites in ornamental art, are very decidedly preferable to the pairs mentioned

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above. With purple, on the contrary, no color harmonizes better than its complementary green.

94. Pairs of colors which form good combinations. Where then shall we find the key to the explanation of these mysterious facts? It would almost appear that we possess such a key in the color-chart divided into twelve parts. For upon investigating the position occupied upon this chart by those pairs which were just designated as superior, it will be found that all the colors in question are separated from each other by an equal number of intervals in both directions, that is to say, by six intervals.

The following table comprises the pairs corresponding to this requirement: —

Purple — Green.
Carmine — Bluish green.
Vermilion — Turquoise-blue.
Orange — Ultramarine.
Yellow — Bluish violet.
Yellowish green — Purplish violet.

These pairs are represented upon Plate IV. They are the same which were formerly supposed to be complementary, — an assumption which a more detailed investigation will show to be *absolutely* true only for the first pair, while for a few others it is only *approximately* true.

All these pairs, which may of course be increased to infinity by intermediate hues, are really good combinations; but a reference to the history of art will nevertheless show that an equal importance does not attach to all of them, for while some of them are continually employed with great predilection in all the best periods of art, others are, on the contrary, met with but seldom.

The most prominent position is undoubtedly occupied by the pair vermilion and turquoise-blue, or, as we will express it for brevity's sake, by red and blue, for the vermilion may also be replaced by scarlet, which is of rather a more yellow-

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ish hue, or even by a color still nearer to red lead, in which case cobalt-blue or a somewhat lighter (colder) ultramarine will have to be substituted for the turquoise-blue.

This combination of red and blue occurs even in the oldest monuments of art, in ancient Assyrian ornaments, for instance, such as the one from Nineveh represented by Fig. 1 on Plate V., and in Egyptian mural decorations. It forms the basis of the most ancient phase of Greek polychromy, and is again found in Pompeii; it may simply be called typical as far as Moresque ornamentation is concerned, and even in Gothic art, in which it is more difficult to discover definite coloristic principles than in any other art, this pair has succeeded in securing to itself the principal position. Into painting proper the combination of red and blue has also found its way; not only did the Venetian painters make an extended use of it, but we meet with it even in the religious paintings of VAN DYCK.

The greater part of the examples cited to show the predilection for red and blue has been taken from architecture. The other pairs are found but sparingly, or even not at all, in this art, while they are, on the contrary, frequently to be met with in textile industry.

Thus the two first pairs, purple and green, and carmine and bluish green, are found in East Indian carpets, while the pairs last named, yellow and bluish violet, and yellowish green and purplish violet, are more particularly employed for silk.

95. Preference given to certain colors.

What then is the reason for this peculiar position of certain pairs of colors? This question cannot be answered before we have once more reviewed the individual colors by themselves, this time from another than the purely physical point of view.

In ornamental art, much more easily even than in painting, we can convince ourselves of the fact that the various colors are in themselves of unequal importance.

Red decidedly plays the principal part. It is *the* decora-

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tive color in an eminent sense. Next to it comes blue, green occupying only the third place, while yellow is employed in the shape of metallic gold whenever feasible, or is at least treated similarly to gold, and very differently, artistically speaking, from any of the other colors. This exceptional position of yellow is also recognized in weaving and in embroidering; for even in the production of woollen textile fabrics, or of embroideries in wool, the yellow parts of the design are always executed in silk.

This point has before been elucidated in detail, and has been brought into connection with the theory of the physiological fundamental colors. But the discussion of the order of succession, in which the colors must be ranged according to their artistic importance, had to be deferred until now, as the reasons here to be considered are of an æsthetical as well as of a physiological nature.

The position occupied by the various colors in relation to surrounding nature appears to be the first point claiming consideration. If we are about to paint an object which is placed in the open air, we shall on the one hand endeavor to distinguish it from its surroundings by the color given to it, and on the other to avoid the possibility of bad combinations with the colors in its neighborhood. We shall therefore have to commence by inquiring what colors are of most frequent occurrence in nature.

The fullest color which we find in nature in considerable quantity is the green of the leaves. Next to green in the order of importance is the blue of the sky, although its degree of fulness is incomparably lower. All the other colors are only transiently represented in larger quantities, during sunrise and sunset, for instance, the rarest of all colors to be met with in nature being a full red. Only a few flowers and a few kinds of fruit exhibit this color, but these are of no importance whatever in the total impression made by the landscape.[16]

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For this very reason red is better fitted than any other color for the purpose of relieving an object in the open air from its surroundings. At the same time it offers another advantage, inasmuch as it forms a good pair with either of the colors green or blue which dominate in nature; and in the two circumstances just named we may therefore seek an explanation for the fact that red holds the first rank as a decorative color.

The relative scarcity of red has probably not been without influence upon the formation or the sensitiveness of our organ, the eye; and it may be attributable to the seldom occurrence of red that the latter is proportionately more exciting than any other color; while on the other hand the absence of green, following upon a previous impression received from it, makes itself felt with especial force, so that the successive contrast is particularly vivid in the case of green.

The fact that green, the fullest color to be found in nature, is also that color which fatigues the eye least of all, accords admirably well with the observations just made.

But the great importance of red in the decorative arts is not only owing to the peculiar position which it occupies in relation to the colors to be found in nature. There is still another circumstance which tends to increase its importance. While green, blue, and violet objects undergo a tolerably great change of hue, and lose considerably in color when illuminated by artificial light, while even yellow fades away and contrasts less with white than by daylight, red retains its brilliancy unimpaired, and does not suffer itself to be dislodged from its prominent position, even by lamplight.

A very similar train of observations will enable us to understand the part played by blue. Taken by itself blue will hardly be used in the open air, since it does not give a good combination with the green of the leaves, and does not contrast sufficiently with the blue of the sky. On the other hand, however, there is at least no injurious contrast between

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it and the sky, and — what is of still greater importance — it makes a good pair with red, the color which is so useful for decorative purposes, and for these reasons its position is assured. Colors which contrast injuriously with the blue of the sky, such as violet or bluish green, for instance, are almost entirely excluded from application to buildings.

The situation of green is much less favorable. While it does not make a good pair with the blue of the sky, it either contrasts too little with the green of the leaves, or forms positively bad combinations with it, on account of the different manner in which green pigments and chlorophyl are influenced by the light falling upon them (see p. 64).

The proposition just advanced, that green harmonizes badly with the blue of the sky, will perhaps be contradicted, and the magic influence will be adduced, which a landscape covered with fresh green, under a cloudless sky, exercises upon every human being. But here we must not forget that the attendant circumstances which act upon the mind in this case are of quite a different nature. The attempt to reproduce such a landscape upon canvas has never yet been made by an artist with impunity, — perhaps the best proof that it is not the harmony of color which enchants the beholder with its peculiar charms.

Several other notable qualities belonging to certain colors remain to be considered. One of these is the varying power possessed by the several colors of exciting our sensitiveness so as to enable us to perceive differences in their respective brightness. This sensitiveness is much more restricted for the colors at the red end of the spectrum than for the more refrangible rays, and the same is true of the changes in hue caused by differences in the illumination. We can easily convince ourselves of this when looking at pictures in galleries. While the warmer hues retain their relative values tolerably well, even under different conditions of light, such changes assert themselves much more vividly in colder hues,

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and especially in blue. A painting may, for instance, be so influenced by the place assigned to it, or by the time of day, that the blue colors occurring in it stand out in unpleasant prominence, and appear to be out of harmony, while the warm colors are much less affected.

This may be one of the reasons why the warm hues are generally preferred to the cold hues.

The great sensitiveness for changes in light and in brightness, which is especially shown by blue, may also be partly attributable to the fluorescence of the retina (see p. 63), as this is excited more powerfully by the blue than by any other hues.

96. Advancing and retiring colors.

Another point to which attention must be called concerns the advancing and retiring qualities of certain colors. If in a pattern made up of equal quadrangles we paint the latter alternately red and blue, the red quadrangles appear to be nearer to the eye than the blue, — a phenomenon which will show itself still more decidedly if the quadrangles are surrounded by tolerably broad black borders.

If the pattern is executed in two shades of the same hue, say dark red and light red, or dark blue and light blue, or gray and black, the lighter parts will appear to advance.

In a very general way it may be said: If the brightness of the colors is (approximately) equal, the warm hues advance while the cold retire; if the brightness is not equal, the light colors advance while the dark retire.

The reason can be given why, under circumstances which are otherwise equal, the colors at the least refrangible end of the spectrum, above all the red, should advance while the others retire. It is impossible for the eye to see fine red and fine blue lines, or a drawing executed in red, and another in blue, at the same time; to be able to see them both equally sharp we must either place them at different distances, or we must vary the accommodation of the eye. Now if we pass

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from blue to red figures, both being represented upon the same surface, and if we desire to see the latter as plainly as the blue, we shall have to make an effort at accommodation, just as if we wished to look at a nearer object; that is to say, we shall have to increase the curvature of the lens by means of a muscle in the eye. This exertion of the muscle leads us to believe that the red figures are in reality nearer than the blue.

In accordance with this observation it will be found that those hues which are situated between the red and the blue occupy also an intermediate position as to advancing and retiring, so that the least refrangible always appear to be nearer than the more refrangible.

A difference in the degree of brightness may, however, not only compensate the effect of the colors, but it may even change it to its contrary. It will therefore be of advantage, under all circumstances, to be clearly informed regarding these influences, so as to avoid unnecessary difficulties in arriving at the aim which it may be desired to reach.

The painter can make use of the properties of the warm and of the cold colors which have just been mentioned in the so-called silhouettes. A silhouette in a warm hue upon a cold ground shows much better than a silhouette of a cold color on a warm ground.

97. Triads of colors. After these general observations, which were principally occasioned by the curious circumstance that not all the pairs of colors mentioned above have been able to attain to the same importance in the arts, although they appear to be all equally good in themselves, we shall now return to the combination of definite groups of colors.

The combinations of two equivalent elements are followed by those of three, the so-called *triads*. If three colors, A B C, are to be so selected that none of the three shall play a more prominent part than either of the two others, the rela-

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tion between A and B will necessarily have to be no closer than that between B and C, and between A and C, as otherwise one of the colors will naturally occupy an exceptional position, while the two others will have to be looked upon as a pair. Combinations answering to the conditions just stated can easily be found by selecting hues from the color-scale of twelve divisions so that there shall be three divisions between each two hues. Taking any hue for the starting-point, and calling it the first, we can form a triad by adding the fifth and the ninth hue.

Proceeding upon this principle, the following triads will be obtained (see Plate IV.):—

Purple, Yellow, Turquoise-blue.
Carmine, Yellowish green, Ultramarine.
Vermilion, Green, Bluish violet.
Orange, Bluish green, Purplish violet.

The first of these triads, that is to say, purple, yellow, and turquoise-blue, was a great favorite with PAUL VERONESE, who frequently employed it. The second, carmine, yellowish green, and ultramarine, is a combination which was very popular among the Italians of the best period. For the yellowish green, however, they selected a somewhat darker shade, which might properly be called olive-green. This triad appears to have supplied the basis for the decoration of the ceiling of the temple of Theseus, judging by the representation given by SEMPER.

The last triad, finally, that is to say, the combination of bluish green, orange, and purplish violet, found frequent application, likewise according to SEMPER ("Der Stil," Vol. I. p. 159), in those silken woven fabrics belonging to the early Middle Ages which are ornamented with barbarous animal figures, and sometimes go by the name of "New-Babylonian."

All of these triads may be enriched by the addition of black and white, or silver, while gold can only be used in connection with those which do not contain yellow or orange. In

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ornaments the two colors last named are replaced by gold whenever possible, so that the further use of this material is very naturally excluded in such cases.

98. Double pairs. With the examination of these pairs and triads the investigation into the nature of such combinations is almost exhausted. For we meet with a peculiar difficulty as soon as we endeavor to proceed still further, and try to group four colors so that each shall be the equivalent of each of the three others. If we follow a course similar to that before adopted, we shall have to select four colors from the color-scale so that each shall again be separated from the one next following by an equal number of intermediate hues, which in the present instance will be two. But if we do this, we shall on the one hand have to deal with intervals which are very apt to become dangerous, while on the other those hues which in this arrangement are six intervals apart from each other will immediately betray a closer relation, so that the whole combination will bear more of the character of two pairs. In such cases it will be advisable to mark this character still more strongly, and thus to avoid those combinations of doubtful value which are made up of colors separated from each other by only two hues.

This end can be reached by selecting four colors which form two good pairs, and which are situated pretty closely to each other upon the color-chart, so that A and A′, and B and B′ (supposing the four colors to be designated by A A′ B B′), shall be small intervals, while A B and A′ B′ represent intervals of the greatest possible magnitude.

This species of combination is frequently met with in the best ornaments. A few examples may serve as an illustration.

Fig. 57 represents an East Indian carpet, richly adorned with embroidery in gold, the covering of a sedan-chair, which forms part of the ethnographic collection at Munich. Fig. 58 is a diagram showing the arrangement of colors adopted in

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this carpet. These colors form two pairs which correspond exactly to the rule just laid down concerning the best pairs.

Fig. 57.

One of the pairs is purple (*Pr.*) and green (*Gr.*), the other consists of a deep scarlet (*Sc.*) approaching almost to carmine, and of turquoise-blue (*T. B.*).

These two pairs, therefore, contain colors which are separated from each other by six intverals of the color-chart of twelve divisions, while the colors which are closely related to each other form a small interval. This so-called small interval is indeed in itself quite considerable, so that it might almost be classed among the "bad combinations," and it

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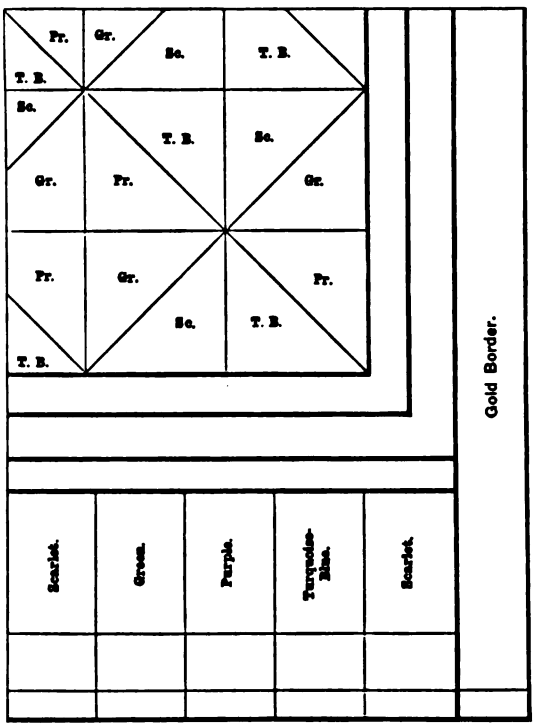
would undoubtedly assert itself as such, if the two colors were allowed to meet without an intervening medium. But

Fig. 58.



as the colors never adjoin each other in lines, and only meet in points, and as they are even there separated from each other by the gold of the embroidery, there is no opportunity offered anywhere for the development of injurious contrast, so that the whole composition is highly successful from a coloristic point of view.

It is also interesting to note that the manner in which the colors are employed in this pattern leaves no doubt as to which of the four colors are to be looked upon as forming

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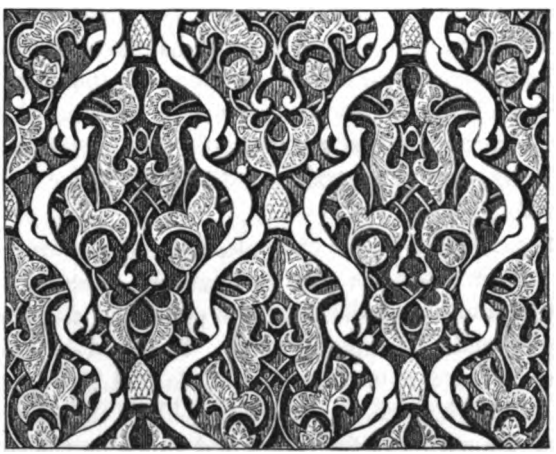
pairs with each other. It will be seen, by reference to Fig. 58, that each of the obliquely placed quadrangles, into which the whole pattern may be resolved, contains always only *one* pair of colors in its four compartments, that is to say, either purple and green, or scarlet and turquoise-blue.

Another species of double pairs may be obtained by adding to two colors either a third color, or gold or silver, in such a manner that in the total impression produced the three will form mixtures.

An excellent example of the origin of this kind of double pairs will be found in Fig. 59, which represents part of a mural decoration in the Alhambra.

Fig. 59.



This ornament, the compartments of which are separated by golden scroll-work, shows conventionalized leaves upon an alternately red and blue ground. The leaf arabesques are likewise red and blue, red leaves being placed upon blue, and blue upon red ground. But these arabesques are again richly ornamented with gold, so that their local color is only visible in narrow lines. Hence the red figures obtain more of an orange-yellow hue, the blue figures a broken bluish-gray

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hue; or, if the observer be so situated that the lustre of the gold can assert itself, the first will produce the impression of a red alloy, the latter that of a whitish alloy.

In reality we therefore find in this ornament, besides the broad scrolls of pure gold, the pairs red and blue, and yellowish red and bluish gray, or, more correctly speaking, red gold and pale gold.

If in similar cases the gold is replaced by black and white, the effects obtained will also be similar. This method of producing apparently new hues with only a few colors by means of true mixture is to be highly recommended, especially for woven fabrics.

The theory of pairs and triads of colors just developed can be put to use in a variety of ways in the art-industries, and above all in the manufacture of paper-hangings, and in weaving. Its principal value will be found in the fact that it offers a ready means for transposing a pattern which has given satisfaction in one set of colors into others by simply substituting other pairs, triads, or double pairs for those first employed.

In Fig. 1, Plate V., for example, the colors correspond to the third pair. But the pattern might be executed equally as well with either of the other five pairs, and still the effect produced would be equally good. It would be advisable, however, in the case of the pairs purple and green, and carmine and bluish green, to substitute gold for the silver or the white of the outlines; for yellow and violet, on the contrary, white or silver would alone be admissible, while for all the others either gold or silver, or perhaps both, in suitable combination, may be employed.

Under all circumstances, however, great care will have to be taken with the pair yellow and violet, when executing such substitutions, as this pair can hardly be looked upon as the equal of the others. Yellow occupies too exceptional a position, on account of its high degree of brightness, to allow

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of its being treated like any other color, without further consideration.

Triads and double pairs self-evidently allow of the same substitution; but we must never lose sight of the fact that corresponding changes in the treatment of the outlines, or of similar elements of the first order, must be introduced simultaneously with these substitutions.

99. The value of outlines. The principles which may be laid down for the combination of colors of the same order would seem to have been tolerably well exhausted by the observations thus far made, for it will be found that cases of a more complicated nature can always be traced back to the simpler ones which we have investigated. The combinations of elements of different orders, however, still claim special attention at our hands.

The principle which governs these combinations of coloristic elements of different orders has already been stated. It consists in this, that such elements must also be employed upon elements of form of different orders.

Such an element of form, and one of especial importance, is to be found in the outline which separates the ornament from its ground. The outline is an essential attribute of decorative art. It enters into ornamentation as an independent and active element; while in painting it is simply an abstraction, which implies nothing but the line of contact between two surfaces of different colors. The bordering of such surfaces by means of a third color undoubtedly owes its origin to purely technical motives. Manipulations, such as joining, cementing, sewing together, hemming, etc., must necessarily lead to outlines. But the great chromatic advantages to be derived from such outlines could not escape the observation, and hence the outlines continued to be employed, even after the technical reasons for them were no longer present, until finally they rose to the dignity of an element in decorative styles.

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The chromatic advantages offered by outlines are quite various.

Borders are very frequently employed, not as a new element serving to enrich the composition, but simply for the purpose of relieving a flat ornament more effectually from its ground, or of aiding the eye in tracing the lines of the ornament. This is especially the case when colored ornaments are executed upon a neutral ground or upon a ground the color of which is closely allied to that of the ornament itself. Under such circumstances it will always be well, by means of suitable outlines, to increase the difference already existing between the two colors.

If in such cases the surfaces were allowed to touch each other without some special means of separation, a mixed color would be likely to result at the boundary lines, and the various parts of the ornament, instead of being sharply defined, would present the appearance of passing gradually into each other. This may be obviated, in cases for example in which the two colors are both of the same hue, by introducing an outline, which is either lighter than the lightest, or darker than the darkest shade.

Whenever the ornament is brighter than the ground, a still brighter outline will produce the impression of a border of light, while one that is darker will act as a slight shadow, and this impression can and must be increased still further by the treatment of the border. In both cases, however, the effect will be to enable the eye to comprehend the design more readily.

The want of a border of this kind asserts itself most vividly when an ornament is executed in fine lines, and in a dark color, upon a light ground. In such an instance the blurring of the outlines, above alluded to, is very apt to produce illusions. The lighter ground appears to encroach upon the figures, more especially upon their narrower parts, so that fine tendrils, the stems of leaves, etc., may seem to be unpro-

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portionately thin, or may even disappear altogether, if they are not emphatically marked in some way or other.

If the ground and the ornament are of different colors, the outline, provided that no other office has been assigned to it than the one above spoken of, must be of a color which is a shade of either the one or the other of the two hues, and which is therefore related to one of the colors employed. If white or black is used for the outlines, the case may be looked upon as one which is situated upon the border between the cases just spoken of, since white and black are the poles of every shade.

The outlines may be dispensed with entirely, whenever the ground or the ornament is black. The same is true of figures in light colors upon a ground that is considerably darker. But in such cases care must be taken not to cover up the ground to excess, if the running into each other of the light colored figures is to be avoided. Ornaments constructed upon this principle, and therefore executed without outlines, are very frequently met with among Pompeian mural decorations.

There are other cases, however, in which outlines become an absolute necessity, as, for instance, in the case of two full colors of different hues adjoining each other. The contrast by juxtaposition (see p. 149), which is of itself sufficient to interfere injuriously with the repose of the total impression, is here accompanied by another circumstance, which likewise demands the presence of borders. It has previously been shown (see § 96) that designs executed in two different colors cannot be seen distinctly at the same time, and that this difficulty increases with the increase of the distance in the spectrum between the two colors. The line of contact of two colored compartments of this kind must therefore invariably appear to be blurred, and from theoretical considerations we might naturally be led to expect that this phenomenon would be most marked in the case of red and

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violet. This would indeed prove to be true if we were operating with the colors of the spectrum; but as a pure violet cannot be obtained from any of our violet pigments, since all of the pigments of this color send out red as well as violet rays, red and blue will be found to be best adapted for the purpose of studying the phenomenon in question. Ornaments executed in these hues without intervening outlines will indeed always produce a sensation of disquietude, in spite of the harmony which subsists between the two colors, — a fact which may easily be verified by looking at Figs. 3 and 4 on Plate V. The artistic feeling inherent in human nature has at all times instinctively recognized this necessity, and hence classical ornaments in red and blue, without outlines, are of very seldom occurrence, although the pair just mentioned is precisely the one which is met with more frequently than any other. This is true, of course, of perfectly flat ornaments only. Whenever a design is executed in relief, the lights and shadows always produced are in themselves sufficient to act as outlines. Owing to this difficulty of finding classical ornaments, which might serve as striking illustrations of the phenomena under consideration, the author has been compelled to substitute red and blue for the colors which Figs. 3 and 4 of Plate V. show in the original.

By the introduction of a dark border the effect of disquietude is immediately removed. But this result is accompanied by still other phenomena. It will be remembered that Figs. 3 and 4 on Plate V. were originally introduced to illustrate the influence exercised by the superficial extent of one color upon the hue of another adjoining it (see description of plates). Fig. 3 shows that the fine red lines upon the blue ground assume a slightly purplish tinge by the mixture of the two colors, while the contrast asserts itself in Fig. 4 (see p. 168).

Both of these effects are reduced by the introduction of

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outlines, but on the other hand it will be observed that a slight mixture of the color of the outline with the colors of the ground and of the ornament takes place, so that in the case of darker outlines these two colors are themselves apparently darkened. This darkening is principally noticeable in the darker color, — a fact which is well illustrated by Fig. 4. The reverse will be observed in the case of lighter borders, thus showing that in both cases the introduction of these simple outlines increases the difference between the two colors which are separated by them.

The most perfect separation of two colors, as well as the best safeguard against the influences just mentioned, can, however, be obtained by very prominent and expressive outlines, such as may be produced by a border consisting of a number of lines. Such outlines, for the execution of which it will be best to select gold or silver, accompanied by black, or by black and white, have the power of separating colors so completely, that each appears in the hue which it would show if seen by itself upon a neutral ground.

A very excellent proof for this assertion is furnished by the ancient Assyrian ornament represented in Fig. 1 on Plate V., and repeated in Fig. 2 with some alterations, the principal one of which is the substitution of blue for the red of the first figure. The two colors in Fig. 1 show neither a mixture nor an effect of contrast; both of them exhibit their natural hue, as upon a neutral gray ground. The same is true of the blue in Fig. 2; while in Fig. 7, where blue is placed upon a black ground without intervening outlines, it looks considerably darker.

To obtain this effect in Figs. 1 and 2 it was necessary to surround the white border by fine black lines. Without the latter it would have been impossible to avoid the blending of the white with the adjoining colors, and the repose of the whole composition would have been destroyed.

These remarks will also serve to give a correct idea of the

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position of gold, and of its substitute, yellow, which has repeatedly been referred to in previous passages.

We will here drop our general observations on the combinations of colors for ornamental purposes. It does not seem advisable to enter into further details regarding the principles which have been laid down, since it is contrary to the spirit of artistic activity to adhere too closely to narrow and conventional rules.

We will rather essay, before leaving the subject of decorative art, to characterize in as few words as possible the leading ideas which may be detected in the coloristic treatment of ornaments in the various historical epochs.

100. Historical sketch of the development of color in ornamental art.

In the very first stages of artistic activity the choice of colors was undoubtedly governed by no other principle than the desire to apply the pigments, or the colored materials at command, so as to produce the richest effects possible.

At a time when technical knowledge is still limited, the number of these materials is quite small, and it is decreased still further from the fact that in these primitive epochs of art taste demands the most intense and fullest colors. Art is therefore compelled by sheer necessity to exercise a beneficial economy in its beginnings.

But with growing skill in the production of colored materials, this same wise economy must become a principle, and taste, which has now become conscious of itself, must supply the law.

Whenever this is not the case, whenever, even with a more perfect development of technical skill, the only desire is to employ all the means at command to the fullest possible extent, the creations of industry must necessarily be barbarous. They may perhaps minister temporarily to a passing whim of fashion, but they will not be able to satisfy the truly artistic instincts of human nature for any length of time.

The disproportion between purely technical skill and sound

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artistic judgment, which has just been alluded to, is a sign of decay, or of an artistic tendency which is fundamentally false.

The oldest monuments of ornamental art, such as they have been handed down to us, although only in fragments, from ancient Egypt and Assyria, are almost totally free from these errors.

The coloristic treatment of some of the ANCIENT EGYPTIAN ornaments does indeed appear to be still somewhat governed by the mere desire for variety. But the number of colors is nevertheless always so limited, and the character of each of these colors is expressed with so much decision, that the danger of untasty combinations is not nearly as imminent as in those cases in which pale or half hues are employed. Besides this, the criticism just uttered is true only of some few flat ornaments. The painting of the shafts and of the capitals of the columns exhibits so excellent an application of the several colors, and shows such an exquisite equilibrium between the superficial extent and the intensity of the colors employed in the decoration, that it is impossible to suppose it to be the product of mere chance, and that we find ourselves compelled to admire in it the result of an artistic intelligence which has acted with deliberation and judgment.

The colors employed are those which are decidedly full, that is to say, red, blue, green, and yellow. At the same time Egyptian ornamental painting stands alone among all the decorative arts, inasmuch as it does not assign an exceptional position to yellow, but employs it just like any other color, and not as a substitute for gold. Probably this peculiarity is closely connected with the fact that the outline plays only a very subordinate part in Egyptian ornament. The colors are not unfrequently placed alongside of each other without an intervening border, — a circumstance the reason for which is undoubtedly to be looked for in technical motives, and the explanation of which may perhaps be deducible from the source from which Egyptian ornament originally sprung.

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The coloristic treatment of the ornament, as practised in ANCIENT ASSYRIA, appears to indicate a still higher degree of development. The ornaments with which we have been made acquainted by the excavations at Nineveh show a wise restriction to a few colors, but these so selected as to harmonize all the better. The border is here introduced as an essential element of ornamentation, which is well understood both in form and in color. Yellow also occurs principally as the color of seams, trimmings, fringes, and tassels, so that we might imagine it to be replaced to good advantage by gold.

In these works of art of the remotest antiquity we meet already with the typical combination of red and blue, applied in a manner very similar to that which is still in favor in Oriental ornamentation of the present day. An exception in this respect is, however, made by the ancient PERSIANS. The works executed by them show a preference for green, which has been preserved even down to our own day, and is still noticeable in Persian rugs, etc.

The oldest phase of GREEK polychromy, which followed upon the still older monochromatic paintings executed in brown and black, seems to have limited itself essentially to the employment of red and blue. At a later period green was added to these, and not only as a full color, but even in half-tints (presuming the chromolithographic reproductions to be reliable), while the prominent parts of the composition were rendered conspicuous by gold.

At a still more advanced epoch of classical antiquity the Oriental principle of polychromy, according to which the various colors, applied to co-ordinate elements, contribute equally towards the total impression, was more and more abandoned, and was replaced by the sober Occidental maxim of a dominating local color.

The mural decorations of POMPEII remind the beholder of carpets of one color, surrounded by borders of somewhat greater richness, and occasionally ornamented in the centre by

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a real painting. But these borders are distinguished rather by richness of form than of color. Very generally they show only *one* color, in the proper sense of the word, in combination with white or black, or at the utmost with yellow.

At the same time the imitation of natural objects in sculpture and in painting asserts its rights, and the shapes of men and of animals, the representations of flowers and of fruit, enter into the ornament, not in conventionalized forms, but as true to nature as possible. Even here, in the artistic productions of the Romans, the germ was laid for that preference of the pictorial (as opposed to the sculpturesque), which at a future time, and down to our own era, was destined to govern Occidental art.

True polychromy has never been able to do without direct contact with the nations of the Orient, and hence everything which has been left to us of polychromic monuments by the EARLY MIDDLE AGES points in its roots towards Byzantium, or at a later time towards Sicily or Spain.

But while the imitation of living beings, although in barbarous and fantastic forms, penetrated more and more into the ornamentation of the Christian art of the early Middle Ages, the Islamitic nations were developing another style, which was as rich and as gorgeous in its execution as it was simple in its fundamental principles.

The ornamental art of the ISLAM purposely avoided all imitation, and for this very reason color was enabled to develop itself much more independently in it than in any other phase of art, the selection of the colors employed being now left entirely untrammelled by external considerations foreign to their nature. The productions of the Mahometan nations are therefore better fitted than those of any other for the purpose of studying the laws of the harmony of color in the abstract. This same reason has also induced the choice of some of the examples cited in the course of our general observations on decorative painting.

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Islamitic art, and indeed decorative art in general, attained its highest development under the Moors in Spain. They have left behind an almost inexhaustible mine of ornamental motives in the Alhambra, the treasures of which have been made accessible to the public at large by the magnificent works of Owen Jones.

The ornaments of the Alhambra form two groups which differ essentially from each other in their coloristic treatment. One of these groups embraces simple mural mosaics, serving as a base for the walls and ceilings. The ornaments of the latter form the second group, and upon them there has been expended a magnificence and a wealth such as only the exuberant imagination of Orientals can conceive of.

In spite of the variety of forms, and of the impression of the greatest splendor produced by these decorations, which are indeed the richest known to us, the coloristic principle followed out in them is nevertheless very simple. The colors employed are limited exclusively to red and blue, decorated with gold. By the addition of a white border, or of a delicate white design upon a blue ground, the effect of an apparently paler blue is sometimes obtained. The colored compartments are imbedded in a rich network of gold, and the latter is again overrun by fantastic leaves and tendrils, which, although executed in the same colors, are nevertheless made to produce new chromatic effects by means of a plentiful use of gold (see p. 203). Looked at from a distance, these ornaments show a slightly purplish hue.

The colors exhibited by the enamelled mosaic dado are entirely different. Stars of a simple form rest upon a white ground, the colors of the stars being almost exclusively supplied by that part of the color-chart which is not represented in the upper walls. All gaudy, intensely full colors are avoided; outlines are wanting; the whole makes the impression of intentional simplicity. Blue, which in connection with gold plays so prominent a part in the sumptuous dec-

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oration of the upper half of the wall, and of the ceiling, is not indeed wholly excluded from these mosaics, but it is only used in dark, broken, or pale tints. Combined with the white of the ground it therefore produces a much colder effect than in the upper parts, where it is employed as a full color, in conjunction with red and gold. Strong reds, however, are totally avoided in the dado, while a prominent part is assigned to green, which is absolutely excluded from the rich ornamentation of the walls. Yellow, as in all mosaics in general, is made use of like any other color. The impression produced by these ornaments as a whole is mostly that of a pale yellowish green, so that a good pair is formed with the color of the upper portions.

Reminiscences of the ornamentation of the Moors in its period of highest development are still to be found among the present inhabitants of the North of Africa. This is especially true of the preference for combinations of red and blue, which prevails to this day, the blue employed being either deep and full, or of a lighter, somewhat pale shade. The Moorish combinations of color have also found their way into the uniforms of the Franco-Algerian troops.

The decorative art of the other modern Oriental nations, all of which are indeed directly or indirectly subject to the influences of Islam, shows more or less affinity throughout to the art of the Moors, which is quite natural, considering that one source is common to both.

It is remarkable, however, that some of these nations exhibit a preference for certain definite colors. The Persians, for instance, have a predilection for green, which was used only very sparingly by the Moors. In the productions of Persian art there are also frequently found broken or pale tints, the employment of which, together with full colors, demands great caution. For this reason some of the Persian patterns remind the beholder of the productions of the Eastern Asiatics, more especially the Chinese, which pro-

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ductions are frequently in bad taste, because the combinations just alluded to have been employed in them.

With the history of Islamitic decorative art the history of polychromy, strictly speaking, may be considered as having reached its end. The Northern nations have never practised true polychromy to its full extent, and one might almost be led to believe that it is impossible for the feeling for color to develop itself without restraint in countries in which nature is but too often wont to paint gray in gray.

It cannot, indeed, be denied that during the MIDDLE AGES there originated a species of polychromy, such as may be seen in stained windows, in painted altars, in the miniatures of books, etc., which was peculiar to the period named. But this polychromy cannot attempt to compete with that of the civilized nations of antiquity, or of the Orientals, as far as the true comprehension of color is concerned.

It is a vain endeavor to seek to discover definite leading principles in the paintings of the Middle Ages. A single combination of colors obtained typical importance in the period under consideration, that is to say, the combination of red and blue, which was extensively used in glass-painting. Yellow was likewise intelligently employed in connection with the combination just mentioned. But it will probably be found that the frequent application of these colors is due quite as much to technical as to purely artistic considerations, inasmuch as it is much easier to produce a good quality of the red glass which receives its color from the protoxide of copper, and of blue cobalt-glass, than of any other.

The same combination of red and blue, however, is also frequently met with in miniatures. But in this branch of art very bad representatives of the two colors were often made use of, especially in the later Middle Ages, a pale, dull, earthy blue being combined with a vulgar-looking brick red (red lead), or with an ugly rose-color. These combinations

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are not seldom seen, even to-day, on the gaudily painted chests and wardrobes found in (German) farm-houses.

Aside from this one regularly recurring combination, which may also be observed in some of the old German paintings, the choice of colors appears to have been governed by no other leading idea than that of the child whose only desire is to get as much variety as possible out of the color-box which it has received at Christmas.

But while in the department of pure polychromy only a moderate measure of success was vouchsafed to the nations of the West and of the North, or to the modern civilized nations in general, their artistic endeavors were directed all the more efficiently to the imitation of natural objects, that is to say, to painting proper.

Since the period of the RENAISSANCE painting proper has ruled even in the domain of the decorative arts. The ornaments of the epoch named show no geometrical figures, painted with full, deep colors, and surrounded by bright outlines. Wreaths of foliage, laden with fruit and flowers, borne and enlivened by the forms of graceful children and beautiful women, or of fantastic animals, the whole spread out upon a warm brown or gray ground, are now employed for the decoration of the pillars, the friezes, and the ceilings of grandly conceived and yet comfortable apartments devoted to the amenities of life.

It need hardly be said that the coloristic treatment of these ornaments is no longer governed by the principles of decorative art in its restricted sense, but rather by those which pertain to painting.

B. — THE ART OF PAINTING.

101. General principles and aims of painting. Painting aims at the imitation of living beings and other objects by means of color, and in some of its forms it uses these imitations as vehicles for the expression of ideas.

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The degree to which an artist is limited in the choice of colors depends largely upon the nature of the subject to be represented. If the subject is to the artist merely an object for imitation, as in the portrait, he will be limited to the colors naturally belonging to his model; but if it is to serve rather as a vehicle of ideas, his liberty will be much less restricted.

In the case of a portrait, including, as a matter of course, the landscape-portrait, the light, the drapery, and the figures are the only elements which are subject to the artist's will. In all other respects he must adhere closely to his model. In a landscape, on the contrary, which is intended to convey a sentiment (Stimmungslandschaft), and to a still greater degree in a historical painting, the choice of the principal colors, their arrangement in masses, etc., is left wholly to the taste of the artist, and he is bound by no laws but those of the pure harmony of colors, or, in other words, by the principles which are the sole guiding star of ornamental art.

These principles have been sufficiently elucidated in the previous section. Nothing remains for us, therefore, but the inquiry into the purely imitative side of art, that is to say, the investigation of those means which must be employed to produce the illusion of a bodily object upon a plane surface. It follows from this that, strictly speaking, we shall have to deal with the naturalistic phase of painting only.

Even the creative artist who draws upon the riches of a poetical imagination for the subjects of his pictures must begin by thoroughly acquiring that technical skill which will enable him to imitate any object with the utmost natural truth; and not until he finally enters upon his chosen labors as a complete master will it be within his province to determine in each individual case to what extent he will make use of this skill in imitation. He must take care not to overstep the boundary line which separates the domain of higher ethical truth from that of mere truth to nature, and

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the violation of which drags the beholder out of the world of ideas down into the realm of vulgar reality. But the *skill of imitation he must possess*, and the attempt to hide the want of this skill under the cloak of so-called idealism is sure to be quite as disastrous as the contrary attempt, which seeks to palliate the poverty of ideas by purely technical perfection, and thus degrades art to the level of mere manual dexterity.

These few words may suffice to forestall all misunderstandings, and to warn the reader that the discussion here following is not intended to be an argument in favor of the purely naturalistic phase of art, although, from the very nature of this work, the phase just mentioned is the only one which can here be considered.

102. The artist must separate the various activities combined in the act of seeing.

The purely imitative artist, whose field is portraiture, must represent all objects upon the plane exactly as he sees them, both as to form and color; that is to say, the painted picture must produce the same effect upon the retina of the eye of the observer as the original.

But the reproduction of that which is seen meets with peculiar difficulties, as the act of seeing is a very complicated process, based partly upon sensual, partly upon intellectual activity (see § 2).

It needs considerable practice to learn to separate these two activities from each other, and it is this faculty of separating which the artist must acquire. He must be able (once more be it said, as long as he confines himself to the portrait) to reproduce upon his canvas or paper the pure sensual impression which he has received, uninfluenced by anything that the activity of his mind may have added during the process of seeing. For such additions he must leave to the beholder, quite as much as they were left to him while he was observing the object of his imitative skill.

The incapability of reproducing the pure sensual percep-

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tion, without any admixture of the results of his own intellectual activity, is a characteristic trait of the beginner.

It is owing to this incapability that the works which originated in the infantile age of art show exactly the same errors which we meet with in the first attempts of every individual follower of art, and in the drawings and paintings of every child.

A few examples will serve to illustrate what has just been said, and will at the same time give us a very good insight into the peculiar manner in which sensual and intellectual activities co-operate with each other in the act of seeing.

103. Instances of the incomplete separation of these activities.

The earlier landscape-paintings of the Middle Ages always bear something of the character of maps. They regularly show a multitude of objects which it would be impossible to see from the point of view selected; they betray, in fact, the endeavor of the artist to give a place in his picture to all the things of the existence of which he has any knowledge. For this purpose he chooses a very high horizon, and gives to his picture the character of a bird's-eye view. Objects which in reality are so situated as to hide each other are represented one above the other. All things which exercise a potent influence upon the imagination are drawn of a size which is entirely out of proportion. Mountains, for instance, are invariably represented too high, and the same is true of castles, fortifications, or towers. In old views of cities, houses and streets can generally be noticed behind the walls, which it would be utterly impossible to see from the outside, but the existence of which was known to the artist.

Exactly the same mistakes are made by every child in its first attempts at drawing. The artist of the Middle Ages, as well as the child, desires to draw what he sees, but both of them draw a great many things of which they only know, and which they do not see.

A building which projects behind another calls up the

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conception of its existence, and this fact misleads the artist into giving a representation of the whole of the building, although only a part of it is really visible. A mountain impresses the mind with its immensity, and the conception of grandeur is again transferred to the drawing by giving too great a height to the mountain, and so on through all the other examples that might be cited.

The reverse of these map-like landscapes is to be found in the old maps themselves, for these have something of the character of landscapes. A map is intended to reproduce the result of an abstraction; it must be divested of the sensual impression, which the natural scenery makes upon the beholder, and must take notice only of the other half of the activities which are called into play in the act of seeing. But it required long-sustained efforts to enable men to do this, — a new proof of the great difficulty which is encountered in the attempt to separate the purely sensual from the purely intellectual part of a perception.

104. Difficulty of separating sensual and intellectual activities.

This separation is indeed a very difficult operation, and its failure is the cause of numberless errors of judgment which all men are equally liable to make.

As a case in point we may cite the fact that the moon appears to us to be larger when near the horizon than when she is high up in the heavens, although it can be shown by actual measurement that the visual angle under which she presents herself (at least as far as the horizontal diameter is concerned) is the same in both cases, and although she will appear equally large in both situations when looked at through a hollow black tube.

The reason for this curious phenomenon is simply to be sought in the fact that the vault of the heavens produces upon us the impression of a very flat cupola, and that we imagine the horizon to be at a considerably greater distance than the zenith. But as in reality the moon is seen under

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the same visual angle, whether she be stationed at the horizon, which we suppose to be farther off, or at the zenith, which we suppose to be nearer, we naturally take her to be larger in the first position.

We are deceived in a similar manner in the case of a light fog. Mountains seen through such a fog, or in a very fine rain, appear unusually large, and this is true also of buildings or of living beings. The reason for these phenomena is again the same. The fog apparently increases the distance between ourselves and the objects, while the visual angle under which they are seen remains unchanged. But as a distant object must be much larger than one nearer to us, if both are seen under the same visual angle, it follows that objects in a fog must appear larger than usual. LIONARDO DA VINCI was already familiar with this phenomenon. (Compare the passage on the apparent size of after-images, on p. 141.)

Our judgment of size depends upon that of distance.

In a perspective drawing of a hall supported by columns, no one will take the more distant columns to be smaller because they occupy much less space upon the plane. If, on the contrary, we were to attach figures of exactly the same size in the drawing to two of these columns, the figure on the more distant column would be supposed to be the larger.

105. Deceptions in regard to color.

In regard to color the artist is liable to be deceived in very much the same manner as in regard to form and size. The mingling of sensual impressions with logical conclusions, or with impressions which have been retained by the memory, is again a prolific source of error.

A knowledge of these deceptions of the judgment is of the very greatest interest to the artist, and the instances of deception as to form and size, which we have so fully investigated, have simply been adduced for the purpose of facilitating the understanding of those relating to color, for in reality they have no immediate connection with the subject-matter of this treatise.

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The deception in regard to *fulness* is that which is most dangerous to the beginner.

Full colors, as we have previously remarked (see p. 194), are very seldom met with in nature. Even those objects which in reality possess a very full color exhibit it but seldom, and only under certain definite conditions. They cannot show it unless they are illuminated by white light, or, still better, by light of their own color, and unless there is an absolute absence of superficial reflection. It is necessary, at the same time, that the layer of air which intervenes between the eye and the object should be of only moderate thickness.

These various conditions are seldom complied with all at once. But still we generally endeavor to discern the true color of the objects seen, that is to say, that color which would be shown if the objects were close by us under favorable conditions of light. We therefore accustom ourselves, when forming a judgment, to take into account quite unconsciously all the circumstances which interfere with the impression made by the color, and consequently imagine that we see the object in its proper hue, even when this is not really the case.

The pictures of a beginner may again serve as an example. In such pictures we shall regularly find that distant trees, say those of a forest situated in the shadow on the declivity of a hill, are painted too green. The beginner knows that trees, looked at near by, are green, and he therefore still thinks that he sees them green, when in reality they may perhaps present nothing but a neutral gray tint. He then persists in maintaining that he paints what he *sees*, while in fact he paints only what he *knows*, that is to say, that which his *memory* tells him in regard to the color of leaves. The practised artist, on the contrary, is fully on his guard against this error, and therefore at once *sees* the proper color. But a person without artistic education, looking at a well-painted landscape, will again see green in this neutral gray tint, because the idea of a forest is called up in his mind by the picture,

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and because his memory tells him that trees are green. If, however, the beginner has already embodied the result of these conclusions in his picture, the unsophisticated observer will repeat the same process of reasoning once more, and the whole therefore has the appearance of exaggeration and untruthfulness.

But these deceptions are not confined to the open air; we are equally liable to be subject to them within doors. A perfectly unsophisticated eye, for instance, thinks that it sees the hangings of a room always in the same color, while this color exhibits an infinite variety of modifications, according to the time of day, or, more generally speaking, according to the light by which the hangings are illuminated. If a child be asked to color the drawing of a room, it will select the color of the wall-paper, and will ignore entirely all the results of the illumination, such as reflections, etc.

In the works of the artists of very early epochs we meet with the same errors. It will be noticed in old paintings, for example, that the draperies are executed throughout in one hue, while the shadows are put in in black, the changes produced in each hue by the effects of light and shade being left entirely unnoticed. There have been individual painters, however, in very remote times, who even then noticed the increase of depth shown by color in the folds of drapery. In the Pinakotheka of Munich, for instance, there may be seen pictures by masters of the old school of Cologne, that is to say, of about the fourteenth century, in which this peculiarity is expressed quite strongly, and indeed almost too strongly.

A similar error of the same kind relates to the carnation; red cheeks being extolled as something beautiful, and the praises of rosy lips having been sung by the poets, an unpractised artist is apt to see the colors in a face which pleases him much fuller and much brighter than the reality will warrant, and for this reason we are sometimes treated to those doll-faces, which might perhaps pass on a fashion-plate, but which are far from being truthful portraits.

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It would almost seem as if lesser artists had at all times been open to the temptation of painting such sweet, rosy little faces, while the great painters knew better. We can gather as much from a passage in PROPERTIUS, in which this poet advises a girl, who was in the habit of painting her face, to emulate the simplicity and artlessness of color which was to be found in the paintings of APELLES.

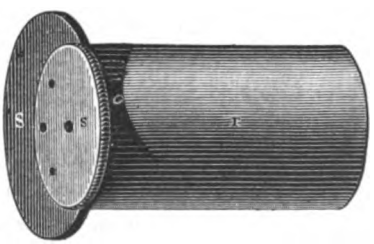
106. Devices for preventing deceptions in regard to fulness.

For the purpose of avoiding this deception in regard to the fulness of color, the artists are in the habit of employing an instrument which shows the object to be imitated almost as if it were itself a picture, and which at the same time reduces its brightness. This instrument is the black glass. By such a reduction of the degree of brightness the effects of contrast, which are less perceptible in a strong light, are also brought out more vividly, and from these effects hints may be obtained as to the hues to be employed.

But as the troublesome phenomena of polarization (see § 38) can never be entirely gotten rid of when using the black glass, the author would recommend another very simple aid, which will answer the same purpose (Fig. 60).

This aid consists of a dark screen which is held close to the eye, and in which there is a very small circular opening by means of which the impinging bundle of rays can be reduced in size. It will be best to make a number of such openings of varying diameter, so as to be able to strengthen or reduce the effect at will. The screen (s) can then be fixed to a larger disk (S) which is perforated in its centre. By rotating s any one of the small openings can be brought into position before the perforation

Fig. 60.



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in *S*. A hollow tube, *r*, which is blackened inside, serves to exclude all side light.

If this little instrument is used in looking at a landscape, or at any other object, it will be quite easy to determine which of the openings gives the best effect of color.

107. Importance of effects of contrast to the artist. All the deceptions here described are the results of the influence exercised upon the judgment by impressions made upon the memory or upon the imaginative faculty in general. The most important, however, are those deceptions which belong to the domain of the theory of color in a stricter sense of the word, and which have been investigated more in detail in the chapter on "Contrast."

With these influences the painter must acquaint himself most intimately, and he must not only be able to detect them in an object which offers itself to his observation, but he must also know how to employ them for producing the desired effect in his own works.

The knowledge of the extent to which these effects of contrast influence the impression made upon the eye by any one object is of especial importance to the artist whose task it is to copy. Supposing such an artist to be engaged upon a painting representing mountains of limestone, to which the setting sun has imparted a somewhat yellowish hue, while the shadows exhibit a deep blue, a want of the knowledge of the effects produced by contrast will undoubtedly lead him to paint the illuminated parts too yellow and the shaded parts too blue, and the consequence will be that his copy will produce a much harder effect than the original.

This is explained by the fact that the yellow parts of the picture have assumed a much more vividly yellow appearance than they really possess, by reason of the juxtaposition of the bluish-gray shadows. These latter, again, are rendered more blue by the juxtaposition of the yellow, so that the difference between the two is enhanced by the effect of contrast. If,

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therefore, the copyist endeavors to reproduce the two colors just as they appear to him under this influence, and if he then places them alongside of each other, the effect must necessarily repeat itself, and the difference will be unnaturally exaggerated.

If the copy be really made with pigments such as are used for painting, the artist will of course detect the influence of the contrast during the progress of his work, and after a little experimenting he may perhaps succeed in correcting his error. But he will be much worse off if the copy must be executed by means which do not allow of subsequent changes, as in color-printing, for instance, or in the weaving of gobelins. In these cases the artist must subtract, from the total effect produced by the original, that portion of it which is due to the influence of contrast, as otherwise he will introduce this effect into his copy with redoubled force.[17]

The creative artist who desires to transfer to canvas a composition which he has completed in his imagination is differently situated. He must know what changes a given hue will undergo when another is opposed to it. Mere experimenting will hardly lead to the desired result in this case; the artist must, on the contrary, construct his composition from the very beginning with a view to the influence exercised by contrast, and he must select his colors, and to a certain extent even his forms, so that they will aid each other in the attainment of the effect desired. He who commences by drawing simple outlines, and only proceeds to color his design when the outlines are finished, will never produce a true painting. His work will at the utmost be an illuminated drawing, more or less pleasing in color. The true colorist will keep both form and color constantly in view from the very inception of his work.

The main secret of a good colorist will undoubtedly be found to lie in this close correlation subsisting between the color and the composition. Upon such a basis the most pow-

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erful and brilliant effects can be obtained even with the most modest of tints, each of which, looked at by itself, might perhaps be called a brown or a gray.

But the artist will anyway be compelled to make use of broken colors. (Compare p. 194 and p. 223.) Nature herself offers hardly anything else to him, and when he comes to the human figure, he will also find that he must be very sparing in the employment of full colors, if he would not destroy the unity of his composition, since the carnation, which plays the principal part in this department of painting, is itself of a broken color. He must never forget that he is bound by the same law which governs ornamental art, that is to say, that co-ordinate elements also demand co-ordinate colors.

Curiously enough some of the adherents of the latest modern school of pre-eminently coloristic and naturalistic tendencies are just at present making some very queer experiments in this respect.

But these broken colors, with which the artist must principally deal, are just those which give rise to the most striking effects of contrast. By availing himself of these effects in a proper manner the artist is enabled to call forth colors which have no longer the character of a pigment, which do not look "painty," and which are therefore admirably well fitted to produce that illusion (see p. 158) which he aims at as the chief end of his labors.

108. Contrast between "light" and "dark." Let us endeavor to gain a clear insight into the principles which the artist must follow if he desires to make the effects of contrast tributary to his purpose.

The first of these principles is the contrast between "light" and "dark" which divides the picture into illuminated and shaded parts, and forms the basis of modelling (that is to say, that part of drawing which imparts to the objects represented the appearance of roundness).

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Generally speaking, and unless some special circumstance should render the contrary necessary, the light, which is the more powerful element, will be concentrated upon smaller spaces, while a greater extent of space will be assigned to the subdued tints of the shadow. Large surfaces of light, with shadows of very limited extent, will but seldom make a favorable impression, and are apt to look flat and restless. Artists therefore prefer to avoid such conditions of light, and even the landscape-painter does not like to select the hour of noon for making sketches from nature, as the effects of light and shade just spoken of prevail at that time of the day.

Various degrees of luminosity, lights, and shadows, — these are the most potent means at the command of the artist for the purpose of imparting relief to, and separating from each other, the objects represented in his painting.

The decorative artist makes his design intelligible by giving different colors to the various parts of his ornament, and by separating them by outlines if necessary. But the painter cannot avail himself of the means last alluded to. To him the outline is simply the ideal boundary at which two differently colored surfaces touch each other upon the picture-plane, while in reality these surfaces are not even situated upon one and the same plane, but occupy positions in space, one behind the other. A difference in color is not sufficient to make this clear to the mind of the beholder; it needs a further difference in the degree of brightness to *bring out* the various parts of the picture, so as to make them appear as if they were situated upon different planes. A painting must be composed so as still to produce the illusion of materiality, even in an engraving, or when executed *en grisaille* (gray in gray).

109. Modelling. The contrast between "light" and "dark" forms the basis of modelling, as we have before observed. Three methods may be employed for this purpose, all of which differ essentially from one another.

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These three methods, which are made use of to relieve an object in a picture from its background, are the following: —

FIRST. The object is made to appear light upon a dark ground, or dark upon a light ground; that is to say, it is treated as a silhouette.

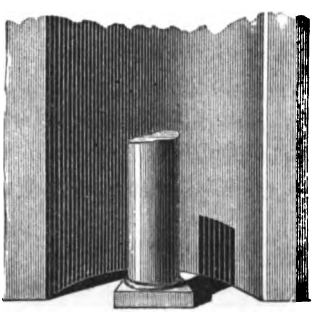
SECOND. The light parts of an object in the foreground are painted lighter than the ground, while the dark parts are painted darker than the ground; that is to say, the differences in brightness in the object are made greater than those in the ground.

THIRD. The gradations of light and shade in the object are represented as being opposed in direction to the same gradations in the ground; that is to say, the bright side of the object is placed upon a dark ground, the shaded side upon a light ground.

The first of these principles is employed comparatively but seldom, for an object treated as a silhouette is apt to look flat, although it is very easy to make it stand out from the ground.

The second method may be found in almost every picture, frequently in connection with the third. The very first figure in this work, for instance (see p. 9), is an illustration of it. Every photographer, who places a gray background of medium brightness behind the person whose portrait he is about to take, makes use of this method.

Fig. 61.



The third principle, however, of which Fig. 61 is an example, is the most effective of all, especially when employed in connection with the second. It was practised most extensively by the great artists of the Netherlands in the seventeenth century.

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Simple as these various methods of distributing light and shade may appear to be, it yet required a very long time to bring them gradually to the knowledge of the artists. The second and third, indeed, were already clearly enunciated by LIONARDO, but the silhouette proper came into use only at a much later period. Strange as it may seem, however, that the human intellect should have been so slow in discovering such self-evident principles, it is nevertheless still more inconceivable, that these same principles should have been forgotten again, after they had once become known, and had been visibly embodied in the works of the great masters. But this was actually the case at the commencement of the present century; for at that time the comprehension of the principles just mentioned had been lost almost entirely, while the comprehension of those more subtile aids, which may be derived from color, was wholly out of the question.

110. Employment of contrast between cold colors and warm colors.

Our investigations into the principles regulating the distribution of light and shade can now furnish us with the key to the laws which govern the distribution of color proper.

To attain greater simplicity and truth, and more especially for the purpose of increasing the stereoscopic effect, it will be found quite as advantageous in the case of color as in that of light and shade, to oppose contrasts to each other. To this end we must divide all the hues at our command into two groups, the one containing the *cold*, the other the *warm colors*.

We have before alluded to this division (see p. 113), and have pointed out that the two groups are obtained by dividing the color-chart into two halves by means of a straight line running from the left side on the upper part, between violet and purple, to the right side on the lower, between yellowish green and green. We shall then have the warm colors on the right side, and the cold on the left. Among the latter we must also include pure white and neutral gray.

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If our only purpose in executing such a division into two groups were the attainment of a certain simplicity and repose in the composition, the line might just as well be drawn in any other direction, which, indeed, is often done in the decorative arts. We need only recall to ourselves the fact that in Moresque ornamentation (see p. 214) purplish violet and yellowish green are opposed to each other in the total effect, as seen in the walls and ceilings, and in the dados, and that these two colors therefore stand in the position of the poles of the two halves, while the pole of the warm colors is orange, and that of the cold colors is turquoise-blue.

Such a proceeding is admissible in decorative art; but in painting the well-known division into cold and into warm hues has a deeper significance, for the atmosphere itself causes this division, and the same contrast is found again in light and shade.

In the open air, and when the sun is low in the heavens, those objects which are illuminated by direct light exhibit warm tints, because the light, in making the long passage through the atmosphere to the object, and back again from the object to the eye, receives a reddish-yellowish hue, while those objects which are illuminated by the bluish reflected light of the sky show cold tints.

A mountain chain illuminated by the morning or the evening sun, especially if the mountains consist of bare rock and are seen at a moderate distance, shows warm lights and cold blue shadows.

As the sun rises, the length of the passage which its rays must make through the atmosphere is shortened, and the light therefore loses its yellowish warm hue. The brightly illuminated parts of objects seen near by, more especially the high lights which are superficially reflected, then assume a cold look, while the shaded parts appear warm in comparison, since all the light received by them comes from terrestrial objects most of which are of a warmer local color.

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The case is similar when we look at the blue sky through a clearing in a forest. The bright sky, that is to say, the most luminous part of the landscape, looks cold in contrast to the shadows of the forest, which receive a warm hue from the trunks of the trees and from the mosses. In general it may be said: Distant objects show warm lights and cold shadows, while objects which are near the observer show cold lights and warm shadows. The nearer the objects the colder the lights and the warmer the shadows. On cold, cloudy, or rainy days the direct light of the sun is wanting, and the bluish reflected light of the sky, or the neutral gray light thrown back by the clouds, preponderates. Under such conditions the prevailing tints in a landscape are therefore cold, and it is this fact, probably, which gave rise to the terms *warm* and *cold*, as they are here used.

But the division into cold and warm hues asserts its rights even in the studio. Here the direct light of the sun is excluded, and the artist, while engaged upon his work, is restricted to the cold bluish light of the sky. But this light is again most noticeable where direct superficial reflection takes place, as upon the shining parts of the eyes, upon hair and skin, as well as upon drapery; while those surfaces which are not illuminated directly by the sun, but which receive their light from the walls and from the floor of the room, have a comparatively warm appearance.

This difference is still further augmented by the warm colors which are chosen for tinting the walls of studios; for no artist who works from a model will ever think of having his painting-room whitewashed, or papered with blue paper. For this purpose warm, and especially brown tints are always selected. Wainscoted ceilings and old Renaissance cabinets, the wood of which is oiled, but not polished, are not mere studio ornaments, calculated to excite the imagination: they also produce a good effect by their color.

An especial significance is furthermore imparted to the

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division into cold and warm hues by the fact that the carnation occupies a very decided position among the warm colors, so that in this case the same contrast is again found between the high reflected lights and the local color.

The artist can therefore avoid the danger of gaudiness, and can at the same time give repose and simplicity, as well as the semblance of truthfulness, to his pictures, by making this division of all hues into two halves (which anyway presents itself to him in nature) the basis of his treatment of color.

If we now inquire into the manner in which these contrasts of "warm" and of "cold" can be used, we shall find it to be very similar to that which is employed in the case of "light" and "dark."

An object of a warm color upon a cold ground, or *vice versa*, corresponds to the principle of the silhouette.

The second method is followed when a neutral tint is given to the ground, while the objects which are nearer to the observer are kept warmer than the ground in their warm parts, and colder in their cold parts.

Finally, the ground and the object to be relieved from it may be so opposed to each other, by toning down in contrary directions, that the colder side of the object appears upon a warmer ground, while the warmer side appears upon a colder ground. Greater differences in the tint of the nearer object, such as correspond to a simultaneous application of the second principle, are quite as admissible in color as in light and shade.

The latter principle, which might perhaps be called the principle of counter-movement in brightness and in color, has been extensively followed by the best colorists, and more especially by those of the Netherlands. It is simply a special application of a much more general æsthetic law, which also asserts its rights in the treatment of the lines in drawing, and even in the management of the various parts in musical compositions.

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It is a curious fact that the division into cold and warm hues leads also in a manner to a division of pigments, those which are used for one group differing essentially from those used for the other. Body-colors always incline towards the cold side, on account of the large quantity of light which they reflect superficially, and of their peculiar character as turbid media; transparent colors, on the contrary, are particularly well fitted for the warm hues. Body-colors are therefore preferred for cold lights, while transparent colors are used for warm shadows. The substantiality of body-colors, that is to say, their *body*, from which they derive their name, is an additional advantage in this case, as it contributes to the prominence of the lights by giving them relief.

But when employing the various methods here described, due care must be taken not to forget what has been said above (see pp. 146 and 166) regarding the efficiency of small differences in brightness as well as in hue. The fact must never be lost sight of that the apparent shifting of a color in the color-scale may be much greater in the case of a small difference in hue than in the case of a much more considerable difference, and that we possess a means of great power in the employment of such small intervals.

111. Circumstances which enable us to see the roundness of objects.

During our discussion of the aids employed to produce a stereoscopic effect in pictures, the question may perhaps have arisen in the minds of some readers, whether it is indeed really necessary to wait until such a peculiar illumination presents itself, or to produce it in the studio, and whether it would not be sufficient to simply reproduce things in precisely those colors which they happen to show at the moment. As nature always makes the impression of bodiliness, it would appear that by a simple, truthful reproduction a strong relief must always be obtainable.

This conception, which we meet with in some of the works of the latest naturalistic school (COURBET, VICTOR MÜLLER,[18]

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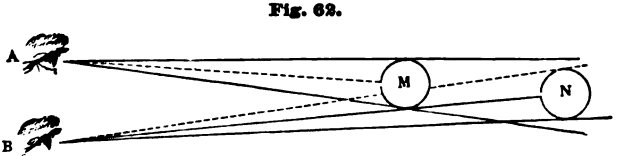
and others), is based upon a very erroneous conclusion, to which attention was already drawn by LIONARDO.

It would be correct if the impression of bodiliness in nature were really produced only by color and by light and shade, that is to say, by the same means which are at the command of the artist. This is not the case, however, for in nature a number of other circumstances are at work which aid us in determining the distances of objects, or of their various parts, or, in other words, which assist us in perceiving the corporeal qualities of the things which we see.

If, for instance, we desire to ascertain the relative position of several objects situated at various distances, we can do so by moving the head or the whole body, as these movements produce unequal apparent changes in the position of the objects, by which changes the judgment is aided. But we possess another exceedingly effective means for perceiving depth in space, even when the body is perfectly at rest, in the mutual activity of our two eyes, a means which is not available to the painter, since he is confined to a plane surface for the representation of his picture.

It is a well-known fact that we look at all objects with our two eyes from two different points of view, and that we therefore really see two different pictures of the same object, or, in other words, that the two perspective views of the outer world which are projected upon the retinæ of the two eyes differ somewhat, so that each of these views has a different centre of vision.

Fig. 62.



This is very clearly explained by Fig. 62, which is a copy of a drawing made by LIONARDO DA VINCI for the purpose of

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illustrating the point under consideration. Two balls, *M* and *N*, are so placed upon a table that only the nearer ball, *M*, is visible to the *left* eye, *A*, of the observer, the more distant ball, *N*, being hidden by *M*. The *right* eye, *B*, however, sees not only the ball *M*, but also one half of the more distant ball *N*.

If we really make this arrangement, and then look at it with unprejudiced eyes, we shall simply see the *two* balls *behind each other*, only that part appearing to be hidden which is also invisible to the right eye. As soon, however, as we close the left and the right eye alternately, we shall find that the view is somewhat different for each.

An analogous case can never be produced by a drawing upon a plane surface; and LIONARDO therefore observes, very correctly, that a painted object can never present the full corporeal appearance of a real object, even with the most rigid adherence to all the rules of perspective and of the treatment of color.

112. The stereoscope. This statement by LIONARDO, which, although quite brief in the original, is nevertheless very easily understood with the aid of the drawing accompanying it, remained unnoticed until the year 1838, when WHEATSTONE, following out the same train of ideas, discovered the stereoscope. WHEATSTONE reasoned very correctly as follows: If two perspective drawings of one and the same corporeal object are offered to the eyes, the two drawings corresponding to the views which the two eyes would in reality receive if looking at the object, and if care is taken that one eye sees only one drawing, while the other sees only the other, the impression produced must be the same which would be produced by the body itself, that is to say, the object must appear to be round.

His conjecture proved to be true, and the stereoscope is now to be found all over the world.

The apparatus which is employed in looking at stereoscopic pictures is not indeed absolutely necessary, and after some

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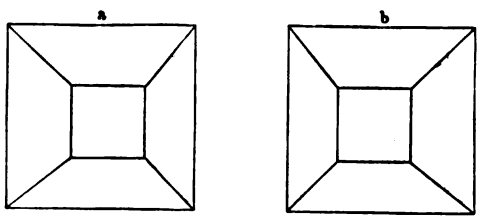
practice it is possible to obtain the stereoscopic effect without any apparatus whatever. For this purpose it is, however, necessary to give an unnatural position to the eyes, and the stereoscopes are therefore provided with prismatic lenses which permit the eyes to retain their natural position, and at the same time serve as magnifying-glasses.

The difference which must exist between the two stereoscopic views belonging together will perhaps be best understood by the following illustration: Let us suppose a truncated, four-sided pyramid to be placed before us upon a table. Looking at this pyramid from above we shall see somewhat more of its left side with the left eye than with the right and *vice versa*. The left eye will therefore see the view *a* of Fig. 63, while the right sees the view *b*. If we now look at *a* with the left eye and at *b* with the right in the same moment of time, we must also see the pyramid. To obtain this effect we must introduce a partition, best of all a piece of dark-colored cardboard, between the two eyes, so that *b* shall be hidden perfectly from the left and *a* from the right eye, and we must then adjust our eyes as if we wished to look at some distant object, while holding the book in a vertical position, which is the best for the success of the experiment. Having done this, we shall instantly see the two pictures coincide, and the truncated pyramid will appear before our eyes with its basis turned away from us, and having the appearance of a model made of fine wire.

Fig. 63.



Those who cannot make the experiment succeed with unaided eyes will of course have to use a stereoscope. But the

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figure will nevertheless serve to illustrate the difference which the two pictures must show.

113. Difference between the means used by nature and by art.

Experiments with the stereoscope prove that we are really essentially aided in perceiving the roundness of objects by the mutual co-operation of our two eyes. But the aid thus received has an exactly opposite effect when we look at a picture, for it then helps us to discover that we are not looking at substantial bodies, and that the objects apparently before us are simply painted representations upon a plane surface. This also explains why paintings obtain a greater relief when looked at with one eye closed, as in this manner we get rid at least of the disturbing influence of binocular vision.

But as it is beyond the power of the artist to present pictures to our two eyes which show the differences necessary to call forth the illusion of bodiliness, it is all the more incumbent upon him to make a more extended use of those other means which assist in producing the same effect.

The landscape-artist must therefore be very careful in the choice of his motives and effects of light, and even when working from Nature it will be well for him to bide his time until he can surprise her in a favorable mood. With an artist working from the living model, it is much the same; for he also must look to it that his light is as advantageous as possible. These maxims, however, are frequently left unheeded by beginners, who undertake to paint things which really cannot be painted; and by the extreme naturalists, who, although some of them are indeed excellent masters of color, so overestimate their own powers, and the possibilities of art in general, that they believe they can afford to ignore them.

The same reason compels the artist to heighten the effects of contrast somewhat beyond nature, and for this purpose the black glass and the little instrument described on p. 225 will be of some service to him, as they will enable him to obtain those degrees of brightness which are best fitted to develop

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contrasts. But such deviations from the immediate impression made by nature are frequently demanded by still another consideration. The differences in the degrees of brightness which are at the disposal of the artist on his palette are immeasurably below those found in nature. To represent the most intense reflected light upon water, or upon the icy surface of a glacier, he has nothing brighter than pure white, which is surpassed in brightness many thousands of times by the lights in question. But in spite of this discrepancy he may nevertheless succeed in imitating these lights if he is sufficiently skilful in the employment of the effects of contrast so as to apparently increase the differences really existing.

114. False naturalism. In short, the means with which the artist must work are not to be compared to those which are at the command of nature, and hence the attempt at a slavish imitation of nature can never meet with success. However loud the representatives of such a short-sighted imitative tendency may proclaim themselves as *naturalists*, their works will always be unnatural! It is the office of the true naturalist to carry the semblance of reality to the utmost limit of possibility, but this end he can only attain by a free, intelligent reproduction of what he has seen, and by a thorough comprehension as well as a perfect mastery of the means which are at the service of art.

115. Historical sketch of the development of color in painting. Having thus discussed the general principles which govern the treatment of color, we will now endeavor to do for painting what we have done in the case of decorative art, that is to say, we will attempt to point out in a few words how these various principles developed themselves in the course of centuries.

During the sway of Byzantine and Romanesque art, as well as in German art of a very early period, painting was still essentially ornamental. It selected its motives exclusively from the sphere of religion, the artist labored solely in the service of the Church, and all his efforts were devoted to the

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decoration of the altar and of the house of God. His chief aim was to make this decoration unsurpassed in richness and in magnificence, and at the same time so to shape it that it might serve to stimulate the imagination of a childlike intellect, and to direct it towards religious subjects.

The artistic means employed were selected accordingly. Highly colored drapery, relieved from a ground of gold simply by its color, without any recourse to modelling, formed the basis of the coloristic composition. Faces and hands, with their naturally subdued color, look strangely out of place in the midst of this gorgeousness; they show very little or no relief, and it is frequently found necessary to indicate their various parts by black lines. The outline, which is of such great importance in ornament, is still made use of in painting. In the earliest period the hems of the garments were usually enriched by golden borders, for which leaf-gold was at first used, while at a later period the gold was imitated. Still later these borders dwindled down to fine golden or yellow lines, but as such they were retained for a long time, and were employed even in epochs which bear an entirely different character (RAFAEL).

The modelling was very imperfect, the shadows cold and colorless, so that these paintings frequently make the impression of charcoal drawings which have been washed in with transparent colors. It has been mentioned before that only some few artists noticed the increase of depth in color in the folds of drapery.

During the whole period of early Christian art painting not only maintained its direct connection with architecture, but was even held in absolute subjection by the latter art. The principles of coloring, therefore, such as they pertain to pictorial art proper, could only be developed after this tie had been loosened, and painting, freed from the trammels of conventional forms, was allowed to follow its own aims.

The larger share of the merit of having led art from mere

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types to the truthful representation of living beings and of surrounding nature belongs to HUBERT and JAN VAN EYCK, two celebrated sons of the Netherlands. They were the first to cultivate a tendency which flourished at a later period in Germany under DÜRER and HOLBEIN, and which still later, that is to say, in the seventeenth century, reached its culminating point in those same Netherlands in which it had originated.

Similar efforts were made in Italy. It will be sufficient to recall the names of MASACCIO, FRA FILIPPO LIPPI, etc., as those of the pioneers of a tendency which was to find its grandest representative in LIONARDO DA VINCI. Lionardo consciously set to himself the task of representing what he saw with perfect truth to nature, and he sought with never-tiring zeal to discover the means which might lead him to the attainment of his aim. Anatomy and perspective, the effects of light and of color, everything, in fact, did he make the subject of his study, and thus he rapidly rose above the level of his contemporaries, while to succeeding generations he became a pilot and a guide.

But his works are nevertheless far removed from naturalism, in the full sense of the word. Indeed, it may generally be said of the Italians of the classical period, that this tendency is but very rarely to be met with in their pictures.

The subjects chosen by them were still predominantly of a religious nature, and hence they allowed themselves, with a just appreciation of the fitness of things, to be guided by architectonic and decorative principles. For the purpose of relieving the figures in their pictures from the backgrounds, which latter were mostly treated with exceeding simplicity, these artists made use of the second only of the three principles spoken of on p. 230, while within the groups themselves they frequently employed also the third method. The draperies are almost always executed in only one tint, and reflected lights, which would have introduced foreign hues, are

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employed but sparingly. By this proceeding comparatively large surfaces of the same color are obtained, which it is easy to bring into harmony with the architectural surroundings, and in which the combination of color must necessarily be treated in accordance with the essential principles of decorative art.

This manner of treatment, far from being attributable to a want of technical knowledge, is rather the result of a well-understood economy in the employment of the means of art; and the plainest evidence of this may be found in the fact that the same artists exhibited a far higher technical skill in the portrait, in which nothing that might be conducive to a greater semblance of reality was left undone.

The culminating point in the truthful reproduction of that which is seen was, however, attained, as we have before remarked, by the painters of the Netherlands, in the seventeenth century. These artists not only did not confine their skill in the imitation of nature to the portrait, but they even exhibited a decided preference, in the very choice of their subjects, for those spheres of human life which do not only admit, but which, on the contrary, demand the application of all technical resources.

In religious or in large historical paintings an ultra-naturalistic treatment is very apt to become detrimental to the idea, as it debases or veils it. But with the representation of some insignificant incident in life, with the *genre* picture, or with still life, the case is different. For these subjects can only be justified, artistically speaking, by the manner of representation, which in them must be carried to the highest degree of perfection.

In this sphere, therefore, the colorist proper finds the true field of his activity. The *genre* painter is indeed much more independent of his subjects than the landscape-painter; for while the latter, unless he confines himself entirely to the lyrical landscape (Stimmungslandschaft), is always bound to

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a certain view, the former can so arrange his figures that they produce the best possible artistic effect, while at the same time they make the impression of perfect truthfulness to nature.

It is nevertheless possible to find a point of view for historical and even for religious subjects which will admit of their being treated in such a naturalistic manner. The most striking evidence for the truth of this assertion is furnished by many of the works of REMBRANDT. But it must not be overlooked that these works are of dimensions completely excluding all idea of a close connection between them and their architectural surroundings. They are easel-pictures in the true sense of the word, utterly divested of everything which might tend to impart to them an ornamental or a monumental character.

The phase of art just delineated gave rise to that school of painting in the Netherlands which threw into the shade all other schools and all other periods, both in regard to truth to nature, and to strength of color.

The great painters who flourished in the Netherlands at this time (REMBRANDT, VAN DYK, TENIERS, etc.) limit the choice of their colors much more closely to the broken hues than the Italians. Their palette consists mainly of those colors which are best fitted to produce simultaneous contrast (see p. 158), and they show themselves to be consummate masters in the manner in which they employ this effect. At the same time they make a very extended use of the apparently insignificant means of "small differences" (see pp. 146 and 166), and thereby avoid all appearance of hardness.

They were the first to introduce the contrast of cold and warm colors as an essential element of coloristic composition.

To the Italian painters of the classical period this characteristic separation of the colors into two groups appears hardly to have been known. LIONARDO DA VINCI never alluded to such a division, nor can a *conscious* application of these con-

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trasts, based upon definite principles, be discovered in his own paintings, or in those of his contemporaries and followers. Only the most prominent of the Venetian colorists, the two PALMAS, TITIAN, etc., might perhaps be exempted from this rule. These artists show a preference for decidedly warm colors, at least in their figures, to which they oppose a cold sky (in the sense of the painter); but even they make a much more limited and much less consistent use of these contrasts than the painters of the Netherlands.

At the same time these great Venetians knew very well how to satisfy the demands of decorative monumental art of the grand style without sacrificing truth to nature and vigor in their treatment of color. Force and refinement of line; grand simplicity in the dispositon of the masses of light and of shade, and of the dominant colors; absence of all gaudiness, not only in the paintings themselves, but also in their decorative surroundings, — these are the distinctive marks of the school in question, such as it developed itself more especially in the halls of state of the palaces of Venice (Palace of the Doges).

It would almost appear as if the progress of art in our own time were also directed towards this aim, and as if Vienna (MAKART[19]) were destined to be the birthplace of a new school of the same tendencies.

The other Italians attached but little or no importance to the contrasts of "warm" and "cold," and it is undoubtedly owing to this circumstance that they made use of the colors green, violet, and purple much more extensively than the artists of the Netherlands. As these hues are the connecting links between the warm and the cold colors, they can be introduced only very cautiously and with difficulty into any coloristic composition which is based upon the division alluded to.

With the artists of the Netherlands the management of the light is exceedingly simple, and yet most thoroughly studied.

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It is one of their favorite methods to concentrate the light upon a comparatively small space. In this manner they obtain large shaded spaces within which variety of detail can be indicated without diverting the attention from the principal parts of the picture. The semblance of reality and of truth is thus produced without any detriment to unity and to repose; while at the same time the æsthetic principle is satisfied, which demands that smaller spaces should be assigned to the more powerful light than to the less effective shadows.

The often vaunted and almost as often misunderstood effect of "chiaroscuro" is based solely upon this simple treatment and concentration of light in connection with transparent, broad, and quiet shadows.

While the men of whom we have just spoken were producing their unassuming but nevertheless great works in the Netherlands, the artists of other countries were likewise engaged in the development of the coloristic side of painting. As examples, we may cite the Italian naturalists, or the Spanish painters, whose efforts were principally directed towards the attainment of powerful effects of color. It is well known that these artists reached their aim by increasing the contrast between "light" and "dark" almost to excess (RIBERA).

In France CLAUDE LORRAIN distanced all others by his peculiar treatment of color. His style is based more especially upon the employment of the silhouette, in the management of which he evinced the skill of a master. His pictures offer hazy backgrounds, which, by a peculiar process of increasing the strength of the light towards a centre, appear to extend far away into infinite space, while against these backgrounds the trees and the buildings, through which the vista opens upon the landscape and the sky, are set off in more sombre tints.

But again there came other times, — times in which the

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heritage of bygone generations seemed to be doomed to oblivion and to decay.

The continued straining after effect, the slavish submission to the whims of courtly fashions, and the undue importance attached to purely technical skill, finally ended in bringing about the ruin of technical skill itself.

With the new century, to be sure, a brighter morning dawned again upon art. The ever-youthful prototypes of the antique were again studied with passionate ardor, and grand monumental undertakings were once more conceived in grand monumental style. But in spite of all this it still appeared, for a considerable length of time, as if the art of coloring had been lost completely.

It was necessary in a measure again to pass through a process of development similar to that which had marked the transition from the Middle Ages to the masters of the Renaissance and to those of the Netherlands of the seventeenth century, although as a matter of course the new development occupied a much shorter space of time and was characterized by peculiar modifications.

But after all it may be said that no new principle has been brought to light since the days of the great masters of old, although the changes which art has undergone are many, and although numberless schools have since arisen, have flourished, and have again decayed.

Individual artists have indeed taken up one or another of the principles long ago known to their predecessors, and have carried them with great success to a high degree of perfection. But it is nevertheless true that these principles have never been applied with more versatility and at the same time with a wiser economy than by the artists of the Netherlands, whom we have now so often alluded to. In view of this fact it may appear justifiable, if the first place in a history of the artistic treatment of color is assigned to these artists, without prejudice of course to the opinions which may otherwise be entertained as to the end and aims of art.

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And here it is meet that this sketch should cease.

Its only purpose was to point out how closely the development of the treatment of color is interwoven with the whole conception and position of art; and how, for this reason, perfection in any one individual work of art can only be hoped for when essence and form, idea and execution, drawing and color, are all as intimately and as organically connected as the parts of a tree, the branches, leaves, and blossoms of which grow out of one parent stem, and draw their nourishment from one common root.

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NOTES.

Note 1.

This statement needs some qualification, lest it should deter the reader from trying the above instructive and beautiful experiment. While it is entirely correct if we wish to obtain a very perfect spectrum, or to show the dark solar lines, yet a very beautiful result may be obtained with very simple means. The slit may be cut with a sharp knife out of cardboard or tin-foil pasted on to glass, or the latter may be smoked or painted black and a fine line scratched on it. Although a prism with faces ground and polished is to be preferred, yet good results may be obtained with prisms of pressed glass, such as may be obtained at a low rate at any optician's.

Note 2.

The sodium-line as seen with a good spectroscope consists of two lines, of which the more refrangible is somewhat the brightest. Between these two in the solar spectrum several other lines are visible, the most conspicuous due to nickel, and most of the others to aqueous vapor. It is claimed by Huggins (Schellen's Spectral Analysis, second edition, p. 170) that one of these lines is due to sodium; but if so, it is not visible in the sodium flame, but requires the higher temperature of the electric light. The latter also brings out several other pairs of lines in the sodium spectrum not visible at lower temperatures.

Note 3.

One of the best illustrations of the effect of thickness on color is in a solution of chloride of cobalt, which when diluted, or when seen in a thin layer, appears pale rose-color, while in larger masses it appears of a rich blue.

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Note 4.

Carl Rottmann, a celebrated landscape-painter of the Munich school, was born January 11, 1798, at Handschuchsheim, near Heidelberg, and died July 6, 1850. His most celebrated works are the twenty-eight frescos, representing Italian scenery, which he executed in the arcades of the "Court Garden," at Munich, by order of the king of Bavaria. These frescos are even now going to destruction, and had to be restored in 1873; the restoration being intrusted to Carl's brother, Leopold. Chromo-lithographic reproductions of the whole series are now in process of publication at Munich.

Note 5.

This effect is admirably shown by the violet aniline ink, so popular a few years ago. Pour a few drops on a plate of glass, and when dry it will appear by reflected light of a rich golden yellow, and by transmitted light, dark purple.

Note 6.

As these works have not been translated, the English reader is referred to the following:—

Ganot. Elementary Treatise on Physics. Translated by Atkinson.

Deschanel. Elementary Treatise on Natural Philosophy. Translated by Everett.

Pereira. Lectures on Polarized Light.

Spottiswoode. Polarization of Light.

Woodward. Familiar Introduction to the Study of Polarized Light.

Note 7.

This statement is not strictly correct, since the light of the sky is never totally polarized. As the maximum polarization of any portion is only about seventy per cent, the reflected beam would never vary more than in the ratio of eighty-five to fifteen at the angle at which the light is wholly polarized by the water. A greater variation would be effected by variation in the angle at which the light falls on the water, which would thus reflect from one hundred to four per cent.

Note 8.

A strong argument in favor of the view that the color of the sky is blue by reflected and not by transmitted light, is found in the color

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seen by polarizing the light. If a Nicol's prism is directed towards the north or south horizon about sunset and turned, it will be seen that the color appears to vary. The sky appears blue when the prism is so placed as to allow the reflected light to pass through it, and brownish yellow when turned at right angles. (Proc. Amer. Acad., IX. 20.)

Note 9.

The statement here made, that a true mixture of colors may be obtained by placing threads of different color into very close proximity, may perhaps need some qualification, for this method cannot be compared in the certainty of its results with the methods described in paragraphs 43 to 46. A number of secondary circumstances are brought into play when threads of different color are worked into each other, and by these circumstances the mixed color apparently produced may sometimes be materially modified. A piece of embroidery, for example, consisting of fine yellow and blue lines, the yellow and blue being so chosen as to produce pure white (gray) upon the color-top, may nevertheless produce a greenish-grayish hue when looked at from a distance. It is not difficult to assign a reason for this phenomenon. For when we examine such a pattern, we shall not only see those parts of the threads which are directly illuminated by daylight, but we shall also look into the furrows which are formed by each pair of contiguous threads. But it will be found that those parts of the threads which are situated within these furrows are principally illuminated by light reflected by the opposite thread, or, in other words, by *colored* light. Under these circumstances the light is necessarily subjected to the same successive processes of absorption to which it is subjected in the successive penetration of two transparent media of similar colors, from which it follows that very nearly the same color must appear in the furrows which would result from the mixture of pigments. The mixed color finally produced by such textile fabrics or embroideries must therefore be sought between the true mixed color and the color which would result from the mixture of pigments. The degree of approximation to the true mixed color will depend on the closeness of texture of the woven fabric or embroidery, and it will be greatest when the disturbing causes just described have been reduced to a minimum. — *Note by the Author.*

Note 10.

A simple form of color-top is made by attaching various colored disks to a child's top, and the phenomena here described are thus admirably shown by very simple means.

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Note 11.

This term of comparison is, after all, empirical, and is merely equivalent to taking sunlight as a standard. The relative brightness of the various colors evidently depends on the source of light.

Note 12.

Single vibrations are probably here intended. The limits of audibility commonly given are somewhat wider. The lowest note of a large organ, or C_{-2}, is given by a pipe 32 feet long, giving 32 single vibrations. The range of a grand piano is from A_{-2} to C_6, or 52 to 4,000 single vibrations. Despretz found the limit of hearing 76,000 vibrations; and Dr. C. J. Blake found that a patient whose tympanum had been perforated still heard a note giving 100,000 vibrations per second.

Note 13.

This statement is perhaps rendered clearer by a reference to the color-chart and the method of studying the mixture of colors, given on p. 103. From this it appears that the combination of any number of colors will appear as a simple color diluted with a larger or smaller amount of white. As precisely the same effect is produced on the retina, whatever components are used to form this color, evidently the eye will be quite incapable of analyzing it.

Note 14.

These limitations are much wider than appears at first sight. Thus in Fig. 64 and Fig. 65, taken from the decorations of the Alhambra, the black and white portions fulfil perfectly the conditions of equivalent elements. They may be shown, however, to come within the definition of rectangles with curved sides, if we make the word "curved" include the case of broken lines, or those formed of several straight lines. Thus the first figure may be regarded as consisting of six black squares placed cornerwise, with each side formed of four straight lines, forming a triangular notch. On two sides of each square this notch indents the black figures, on the others the white. In Fig. 65 the sides of the squares are formed of two lines of unequal length at right angles. The corners of the squares are at the points where four lines meet. An infinite variety of very beautiful patterns may readily be constructed of such squares, giving the sides various forms. Similar figures may be constructed of triangles or hexagons.

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Fig. 64.

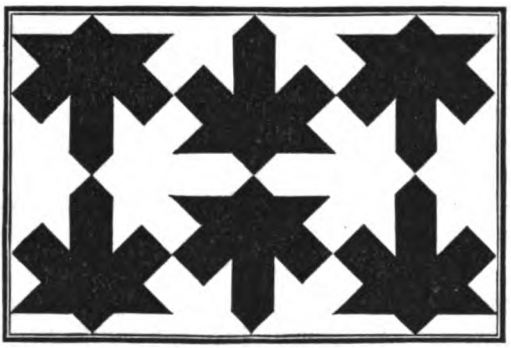
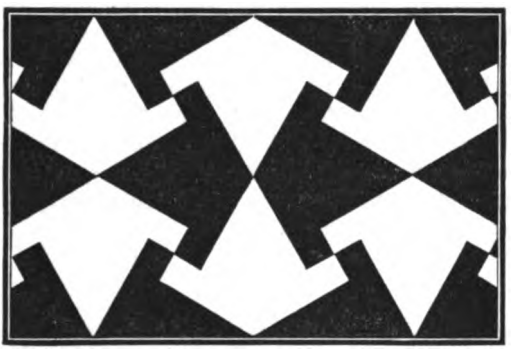


Fig. 65.



Note 15.

How far our tolerance of the discords due to temperament is a matter of education, is still a question. The chords of a euharmonic organ made by Mr. Alley, of Newburyport, are sweeter than those of any tempered instrument even to an ear not very sensitive to discords. The beauty of string quartettes and of four-part songs sung without accompaniment is also ascribed to their freedom from temperament. This, however, merely strengthens the argument given in the text.

Note 16.

It must be remembered that this was written in Germany, and that the author never saw the glories of an American autumn, when red becomes so prominent a color in the woods and forests.

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Note 17.

This difficulty may be remedied by laying on the object to be copied a sheet of gray or neutral-tinted paper, with a small hole in it. The true color of any portion unaffected by contrast may thus be readily determined. A second similar sheet should also be laid on the copy. Another method, employed by Mr. Alvan Clark, consisted in placing bits of painted canvas upon the object, until a perfect match was found. The color, unaffected by contrast, could then be copied direct.

Note 18.

Victor Mueller was born at Frankfort on the Main in 1829, and died December 21, 1871. He commenced his studies at the Staedel Institute of his native city, but at the age of twenty went to Antwerp and afterwards to Paris, where he became the pupil of Couture. Some of his earlier pictures appear to indicate by the choice of subjects that Mueller shared the almost morbid and somewhat sensual tendencies of many of our modern colorists. Of his later works the following are the most important: "The Muses and Graces," "Hero and Leander," "Hamlet in the Graveyard," and his last painting, "Romeo and Juliet." The German critics agree that Mueller was an artist of most uncommon talent, but the passage in the text shows that all his undertakings do not pass unchallenged.

Note 19.

Hans Makart was born at Salzburg, May 29, 1840, and though but little known in the United States, probably enjoys a wider reputation in his own country than any other living artist. His talent for color is well shown in his works, "Roman Ruins," "Modern Amorettes," and "Seven Cardinal Sins," though the latter raised a perfect storm of criticism, favorable and adverse. In 1869 he took up his abode in Vienna by invitation of the emperor, and there painted "Catherine Cornaro at Venice." It must be admitted that his drawing is defective, and that in the specimens of his work which have been exhibited in this country ("Abundantia") he has obtained harmony of color by using only the warm hues. On the whole, Makart may be cited as another example of the curious tendency toward morbid sensuality shown by many of our modern colorists.

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LIST OF BOOKS AND ESSAYS

USED IN THE PREPARATION OF THIS WORK.

For the first four chapters there were used: —

Helmholtz. Handbuch der physiologischen Optik. Leipzig, 1867. (French translation by Javal and Klein, Paris, 1867.)

This work gives a complete exposition of the present state of the science to which it relates. It also contains exhaustive references to the literature of the subject from the most ancient times up to the year of its publication. Of the works and essays quoted by Helmholtz, as well as of later publications, the following are especially noteworthy: —

Isaac Newton. Optics. London, 1704. — Lectiones opticae.

Göthe. Beiträge zur Optik. — Zur Farbenlehre. — Geschichte der Farbenlehre.

Dove. Farbenlehre und optische Studien Berlin, 1853. (Contains an excellent refutation of Göthe's theory.)

H. Grassmann. Zur Theorie der Farbenmischung. Poggendorff's Annalen der Physik. Vol. LXXXIX. p. 69.

J. C. Maxwell. Experiments on colour as perceived by the eye. Transactions of the Royal Society of Edinburgh. Part II. p. 275 (1854-55).

J. C. Maxwell. On the theory of compound colours and the relations of the colours of the spectrum. Philos. Transactions of the Royal Society of London. Vol. CL. p. 157 (1860).

J. J. Müller. Zur Theorie der Farben. Archiv für Ophthalmologie von Arlt, Donders und von Gräfe. Vol. XV. 2d division. pp. 208-258. Poggendorff's Annalen. Vol. CXXXIX. pp. 411-431 and 593-613.

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W. v. Bezold. Ueber das Gesetz der Farbenmischung und die physiologischen Grundfarben. Poggendorff's Annalen. Vol. CL.

Seebeck. Mangel des Farbensinnes bei manchen Personen. Poggendorff's Annalen. Vol. XLII. pp. 177–233.

W. Preyer. Ueber anomale Farbenempfindungen und die physiologischen Grundfarben. Pflüger's Archiv für Anatomie und Physiologie. Vol. I. pp. 299–329.

H. Burkhard und C. Faber. Versuche über die zu einer Farbenempfindung erforderliche kleinste Zeit. Pflüger's Archiv. Vol. II. pp. 127–142.

Dobrowolsky. Die Empfindlichkeit des Auges gegen Unterschiede der Lichintensität verschiedener Spectralfarben. Monatsber. der Berl. Acad. der Wissensch. für 1872. pp. 119–122.

Beetz. Ueber die Farbe des Wassers. Poggendorff's Annalen. Vol. CXV. p. 137.

Hagenbach. Untersuchungen über die optischen Eigenschaften des Blattgrün. Poggendorff's Annalen. Vol. CXLI. p. 245.

Lommel. Erythroscop und Melanoscop. Oekonomische Fortschritte. 1871. Zur Frage über die Wirkung farbigen Lichtes auf die Assimilationsthätigkeit der Pflanzen. Ebendas. 1872.

v. Pettenkofer. Ueber Oelfarbe und Conservirung der Gemäldegallerien durch das Regenerationsverfahren. Braunschweig, 1870.

Strutt. Some experiments on color. Nature, III. pp. 234–236.

J. Sachs. A text-book of botany. Oxford. Clarendon Press, 1875.

H. Vogel. Lehrbuch der Photographie. Berlin, 1870. (English translation under the title: Handbook of Photography.)

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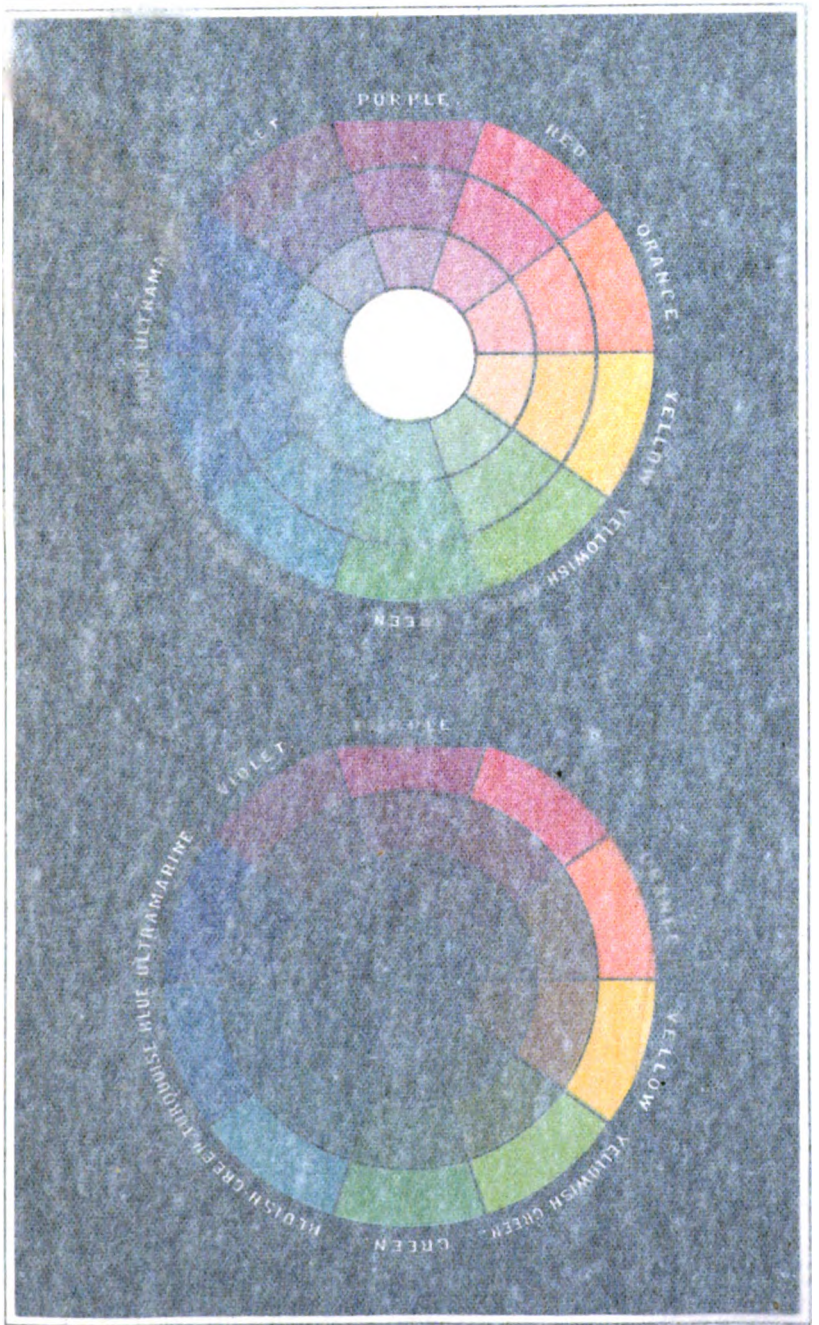

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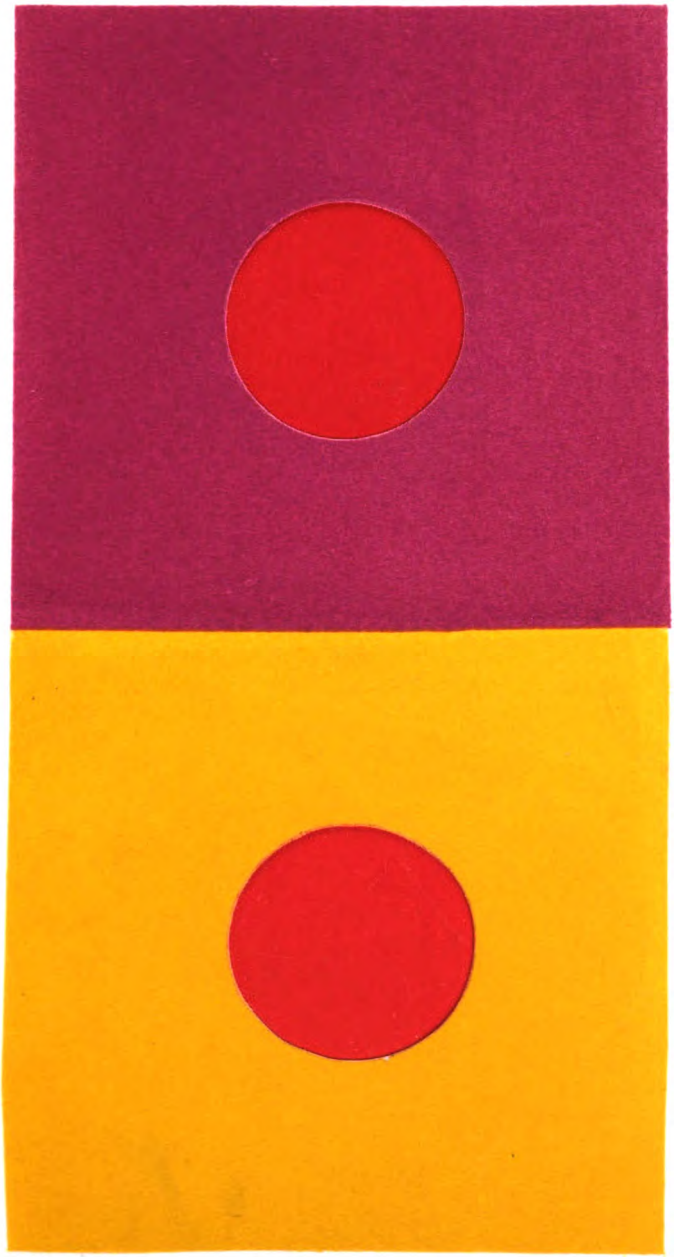

On this plate the two red disks appear to be both of the same color. This plate must not be exposed to a strong light for any length of time, as the purple is liable to fade.

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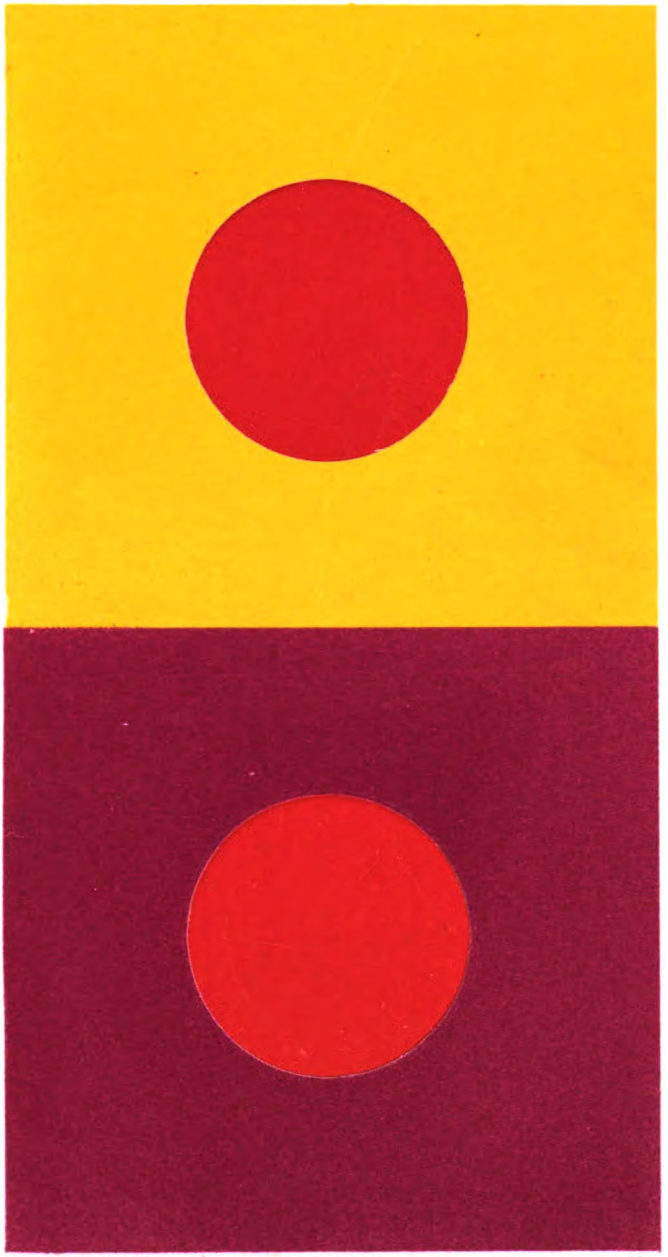

On this plate the red disk on the yellow ground appears to be considerably darker than that on the purple ground. A change in hue is also noticeable.

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On this plate the two red disks appear in their proper colors, uninfluenced by contrast.

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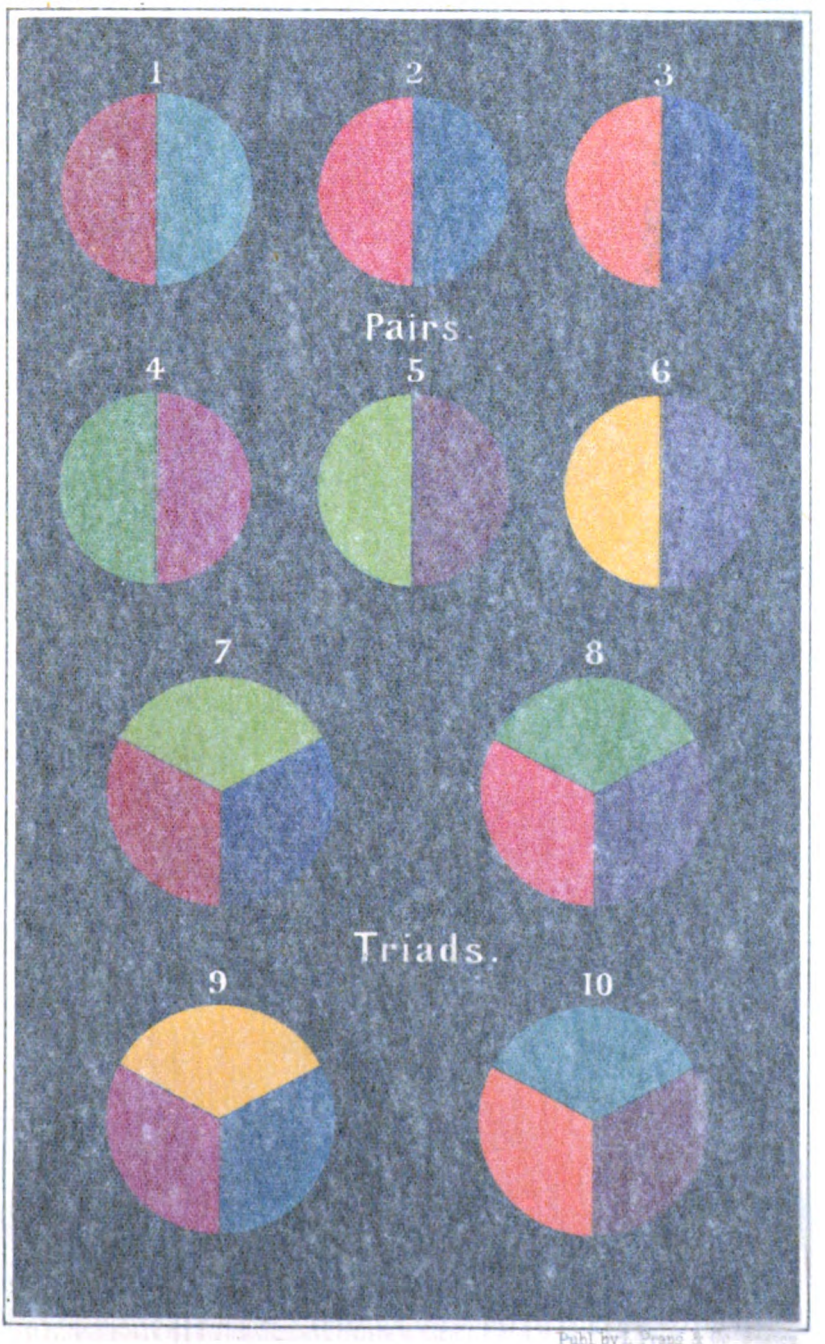

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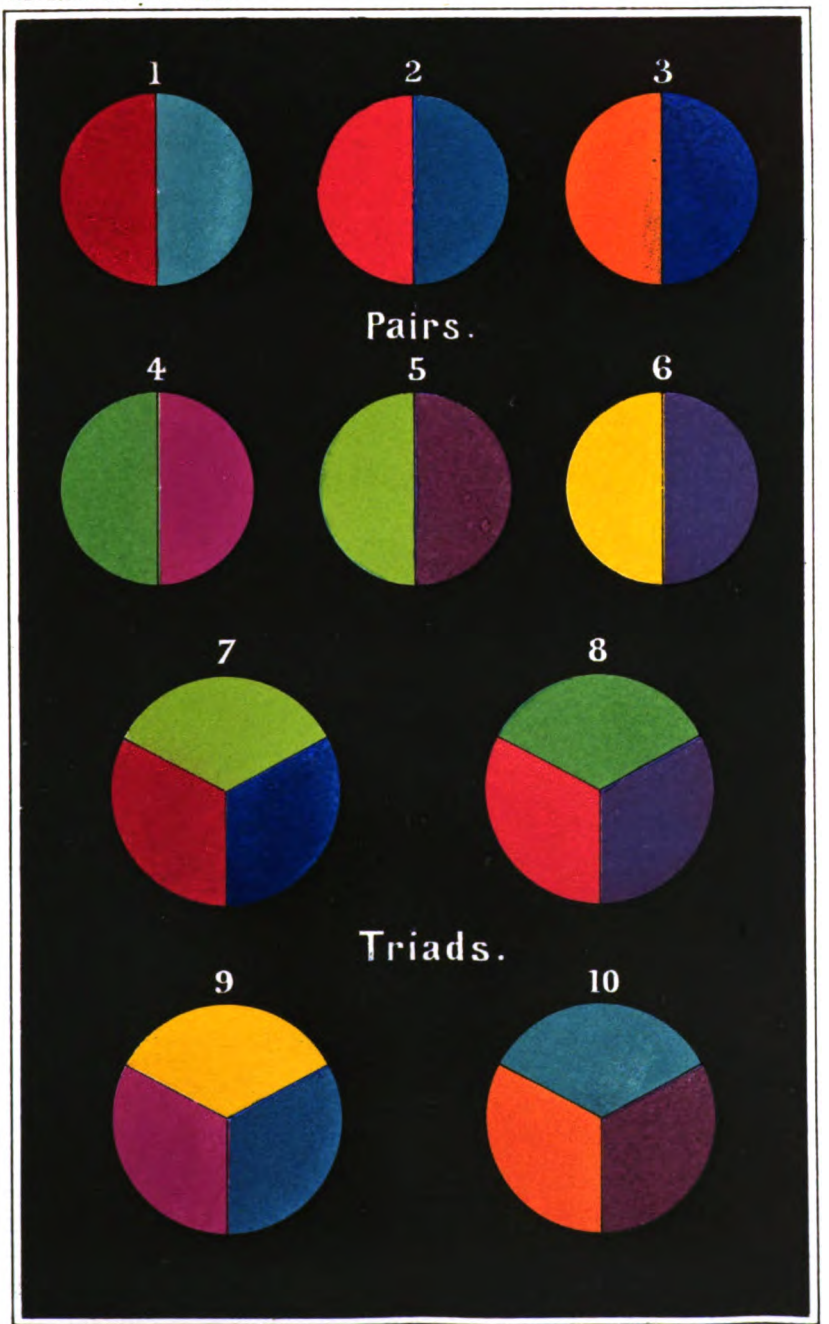

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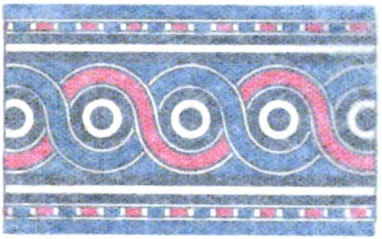

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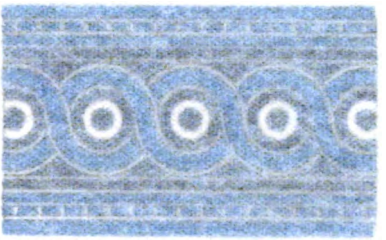

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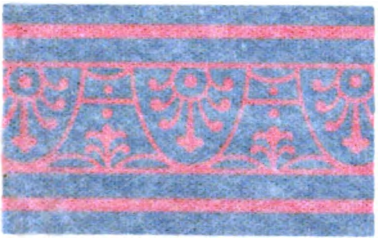

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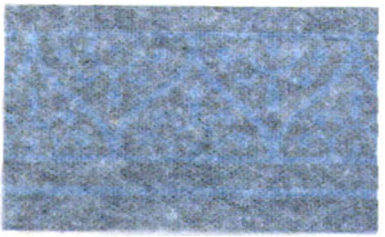

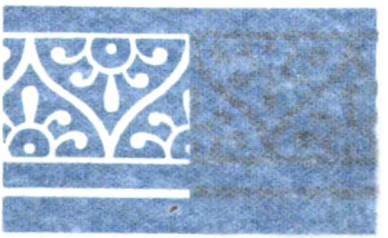

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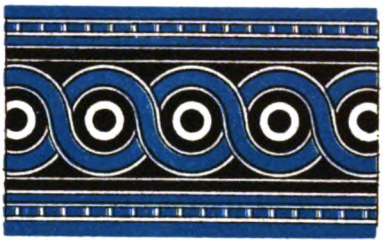

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BLACK

type, on a

RED

ground, seen through white tissue paper, assumes a tinge of

BLUISH GREEN

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PLATE VI.

BLACK

type, on a

RED

ground, seen through white tissue paper, assumes a tinge of

BLUISH GREEN

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YELLOW

ground, seen through whi

paper, assumes a tinge

BLUE

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BLACK

type. on a

GREEN

ground, seen through white tissue paper, assumes a tinge of

PURPLE

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PLATE XI.

BLACK

type, on a

PURPLE

ground, seen through white tissue paper, assumes a tinge of

GREEN

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